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Recommended Strain Gage Application Procedures for Various Langley Research Center Balances and Test Articles

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ABSTRACT: The NASA Langley Research Center uses more than 10,000 strain gages per year in supporting its various research programs. The character of the testing at LaRC is such that the types of strain gage installations, the materials they are applied to, and the test environments encountered, require many varied approaches for installing strain gages. These installations must be accomplished in the most technically discerning and appropriate manner. This technical memorandum is offered as an assisting guide in helping the strain gage user to determine the appropriate approach for a given strain gage application requirement. Specifically, this document offers detailed recommendations for strain gaging the following: **LaRC-designed balances, LaRC custom transducers, certain composite materials and alloys, high-temperature test articles, and selected non-typical or unique materials or test conditions.**

INTRODUCTION: The continuative and challenging demands in the area of strain measurements utilizing resistance strain gages dictate that gaging materials and application procedures for strain gage installations be periodically updated. New materials to be tested over a broader range of temperatures with more demanding test environments has brought about the acquisition of new types of gages and ancillary gaging materials. Procedures and techniques for using these new gages and materials are continually being derived and successfully utilized. Following is a compilation and description of the strain gage application procedures that have emerged in recent years. A portion of this document details processes developed at Langley for gaging new types of engineered materials including high-temperature composites. It should be noted that many of these new application techniques have evolved from methods that were utilized in an original internal NASA Langley document titled "Recommended Strain Gage Application Procedures for Langley Balances, Transducers, Composite Materials, and High-Temperature Test Articles", dated April, 1994. <u>It should also be noted that while this memorandum offers gaging techniques for many test scenarios it obviously does not and can not encompass all of the gage application requirements that arise.</u>

EXPLANATION OF "APPLICATION CLASS" & "INSTALLATION TYPE" : The following recommendations for installing strain gages are listed and described by **"APPLICATION CLASS"** with **"INSTALLATION TYPE"** within the class designated. For this document, there are five distinct classes of strain gage application. Within each application class there are several installation types. Each of the five classes of application with their respective installation types are detailed. As appropriate, gaging materials (including gage type), surface preparation, installation techniques, wiring considerations, gage coatings, and laboratory testing of the installed strain gages are presented. In some instances deviations from these materials and procedures will be necessary. When deviations are deemed necessary, they should be reviewed and approved by the test engineer requesting the strain gaging task.

NOTES RELATING TO THE TEXT FOR THIS TECHNICAL MEMORANDUM:

1. These strain gaging procedures apply only to <u>new</u> gage installations as opposed to <u>regaging or replacing of gages.</u>
2. Balances and transducers requiring <u>complete</u> regaging will be an exception to note #1. In these instances, the appropriate procedure detailed in this memorandum would be applicable and adhered to.
3. The recommended materials for surface preparation for strain gage installations are continually being updated. Therefore, the materials listed for "Surface Preparation for Gaging" are those that are <u>currently being used and are subject to change</u>.
4. When "room temperature" is stated with respect to gage installation procedures it is understood that the actual temperature of the article being strain gaged and the surrounding air temperature is at least 72°F and not more than 80°F. It is also understood that the relative humidity is never more than 40% in the work environment.

RECOMMENDED STRAIN GAGE APPLICATION PROCEDURES LISTING

ADDENDA:

1. "Matching Cryogenic Strain Gages" (excerpt from "Force Instrumentation for Cryogenic Wind Tunnels Using One-piece Strain Gage Balances", ISA, 1981 and "Matching Cryogenic Strain Gages", update to LaRC/ETTD Technical Files, 1984)

2. Instructions for the Application of Micro-Measurements M-Bond 450 Adhesive, Bulletin B-152 (Reprinted by permission of Measurements Group, Inc., Raleigh, NC, USA)

3. Strain Gage Installations with M-Bond 200 Adhesive, Bulletin B-127-13 (Reprinted by permission of Measurements Group, Inc., Raleigh, NC, USA)

4. Strain Gage Installation Procedure Developed For LaRC Gage (excerpt from "NASP Mid-term Technology Review" NASP, 1992)

<u>APPLICATION CLASS I</u> - GAGE INSTALLATION PROCEDURES FOR ALL LANGLEY DESIGNED BALANCES

INSTALLATION TYPE 1 - The following materials and procedures are applicable for STANDARD LANGLEY 6-COMPONENT STRAIN GAGE WIND TUNNEL BALANCES operating in the temperature range of 0°F to 200°F. Apparent strain corrections are made for the temperature range of 80°F to 180°F.

NOTE: Consideration is being given for a class of balances that would routinely operate at temperatures between 200°F and 300°F. For these balances, the application procedure described in <u>APPLICATION CLASS II</u>, INSTALLATION TYPE 3 can be used as a guide.

<u>Gaging Materials (all materials that are an integral part of the balance)</u>

1. Gage type: to be designated by design engineer, typically type: C-891113-A (Micro-Measurements)
2. Adhesive type for gaging: M-BOND 610 (Micro-Measurements); adhesive type for PRT's when required EA-934 (Hysol)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of balance determines which size(s) are to be used
4. Insulation Pads for Apparent Strain and Zero Correction Wires, when required, type: Kapton, 1-mil, etched
5. Gage-to-Terminal Jumper Wire: AWG#40 silver-clad copper
6. Apparent Strain Correction Wire (when required) type: nickel; size determined by amount required for correction
7. Zero Offset Correction Wire (when required) type: Manganin (Driver-Harris); size determined by amount required for correction
8. Intrabridge (between gages) and Interbridge (between bridges) Wire: AWG#30(7-38), #32(7-40), or #36(7-44) consisting of 7 strands of silver-clad copper wire with teflon insulation; size selected will be determined by balance size. Some small balances will require single conductor solid copper, AWG#40 or AWG#42.
9. Exit Lead Wires (when required): Size and length determined by design engineer
10. Balance to Tunnel Connector: to be designated by design engineer, user facility dependant
11. Solder type: 361A (Micro-Measurements)
12. Thermocouples (when required) type: "J" size AWG#36, with teflon insulation
13. Platinum Resistance Thermometers (PRT's): EL-700T (HY-CAL) ; if required
14. Protective Gage Coating type: Gagekote #8 (JP Technologies)
15. Protective Sleeving over Exit Lead Wires (when required): nylon or fiberglass, as per the design engineer

<u>Surface Preparation for Gaging</u>

1. Degrease the entire balance. This is currently accomplished with a vapor degreasing solvent rinse type: ENSOLV (Envirotech, International).
2. Perform microscopic examination of the balance looking for flaws in surface, cracked beams, sharp edges, etc.

3. Rinse the balance with pure alcohol.
4. Mask appropriate areas of the balance for micro-sandblasting operation.
5. Micro-sandblast areas to be gaged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the ENSOLV and alcohol rinse operations. Installation of the gages should begin immediately following this step.

Installation of the Gages

1. Gages, pretrimmed wiring terminals, and insulation pads (when used) should be cleaned with pure alcohol, dried, and placed on a clean glass plate, inverted with the undersides up and ready for installation.
2. Apply a coat of M-610 to the underside of the gages, terminals, and insulation pads (when used) to be installed, as well as a coat to the appropriate balance surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature (assumes air temperature and balance temperature to be no less than 72° F and relative humidity to be not more than 40 percent).
4. Place the gages, terminals, and pads on the balance surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages, terminals, and pads are located.
6. Apply a constant and uniform pressure of 60 psi to the rubber pads using an appropriate clamping device.
7. Place the balance in a temperature chamber and slowly raise the temperature of the balance to 340° F. This heating rate should be approximately 6° F/minute.
8. Hold the balance at this temperature for one hour, then, cool the balance by simply opening the chamber door.
9. Once the balance is cool, remove the clamping device, the rubber pads, and the tape. Microscopically, inspect the gage installations for accuracy of gage positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gage on the balance is typically +/-.005" of the designated location as per the balance strain gage drawing unless otherwise stated. If there is any concern with respect to the integrity of the installation or the accuracy of the gage positioning, the gage must be replaced.
10. More than one cure cycle will be required to install all of the gages on the balance. The gaging areas that will require gages during the subsequent curing cycles should be micro-sandblasted again, prior to each gage installation operation, repeating the surface preparation steps previously outlined.
11. To post cure the gage installations, slowly raise the temperature at the same heating rate utilized for the gage installations until a balance temperature of 340° F is reached. Hold the balance at that temperature for two hours. Cool the balance and repeat the microscopic inspection of the gages.

Wiring the Balance

NOTE: Because of the considerable variation in balance design and size it is not possible to itemize and detail a standard wiring procedure for all Langley balances. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage, to two decimal places, at the gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these balances should be performed using the NASA soldering handbook "NHB

5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All strain gage wiring for balances should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be >10K Meg ohms.
7. All intrabridge (between gages) and interbridge (between bridges) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires should be of equal resistance and length.
9. All intrabridge wires should be snug against the balance surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the balance. When wiring a balance designed for light loads, care must be exercised in preventing the wires from carrying any part of the load being applied to the measuring beams. (Later, when applying the moisture-proofing, do not allow it to bond the wiring to the load carrying beams).
10. Wire routing should be preplanned with no wiring routed over the strain gage active grids or the gage jumpers.
11. When all wiring is completed the balance should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the balance components to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be >10K Megohms. This measurement should be made with an appropriate leakage to ground tester; a high resistance meter generating 15 volts DC potential @ 20Megohms is recommended.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the balance when in service. For each balance component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit. The zeros should be within +/-.050mV/V of the calculated zero. This agreement may be harder to achieve on smaller balances where lightly loaded beams and small intrabridge wiring can affect the calculated zero.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the balance drawing. The typical allowance is +/-.4mV/V.
4. Mechanically shunt each gage within a bridge while observing its electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the balance.

Elevated Temperature Soak Cycle

Prior to conducting apparent strain runs a temperature soak of the completely wired balance is to be performed at a temperature of 200°F for 4 hours. After the balance is cooled to room temperature, , check the zeros against the zeros recorded in Step 2 above. A large change in zero in a given component (>.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change. Once the elevated temperature soak cycle is completed, proceed with the apparent strain correction.

<u>Apparent Strain Correction</u>

1. Place the balance in the temperature chamber horizontally, in the -Normal Force up position, supported at the non-metric end only.
2. The balance should be covered with a non-contacting encasement uniformly constructed such that the balance is not directly exposed to any air flow.
3. For monitoring temperature during the run, attach a thermocouple to the top of the balance in the area of the aft shoulder of the aft cage section using a piece of aluminum tape. If the balance has its own thermocouples or PRT's, utilize the aft one.
4. Connect the balance to the data acquisition system (bridge voltage is to be the same as that which will be used for the complete balance load calibration). Allow this set-up to stabilize for several minutes.
5. Start the "temperature versus output" recording with the temperature chamber air flow on and the chamber temperature controller set at 80° F.
6. Continue recording the room temperature outputs until all component zeros are stable, i.e., not changing more than .005mV/5VDC/5minutes. The temperature on the monitor thermocouple (or PRT) should also be stable.
   NOTE: The monitoring thermocouple (or PRT) on the balance should be brought to within +/- 2° F of the required 80° F prior to commencing the temperature excursion up to 180° F.
7. Turn the temperature controller setting to 180° F and allow the balance to heat until a stable temperature, within five degrees of the 180° F target temperature, is indicated with the monitoring thermocouple (or PRT) on the balance. The heat-up rate should not exceed 6° F/minute.
8. Allow the balance to soak at the elevated stabilized temperature for at least fifteen minutes. For larger balances, a longer period of time may be required to stabilize the balance zeros at the required elevated temperature.
9. Following stabilization of all zeros at the 180° F target temperature, cool the balance to room temperature adjusting the temperature chamber controller as necessary to bring the actual balance temperature to the same temperature (within +/- 2° F) that was recorded in Step 6.
10. On a worksheet, use the recorded apparent strain run to record the output of each component at 180° F with respect to the 'return to room temperature' zero.
11. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm of the bridge circuit to nullify the apparent strain of the bridge. The tolerance allowed for apparent strain is provided on the gaging drawing. This is typically +/-.005mV/V/Δ100° F.
12. Make another apparent strain run as per Steps 1 through 11.
13. After verifying that the apparent strain outputs are within the design engineers specifications for all components, install the moisture-barrier protective coating (procedure reviewed in next section) over the gages, solder joints, and wires as appropriate and place the balance back in the temperature chamber. Conduct an initial apparent strain check run with the protective coating in place.
14. Make another apparent strain run for the balance as per Steps 1 through 11. This run is made in order to confirm repeatability for consecutive apparent strain runs. All respective components should be repeatable (with respect to the previous run) within +/-.003mV/V throughout the entire temperature excursion. Once this specification is met, that run becomes the final apparent strain run. Following a final microscopic examination the balance should be ready to be forwarded to the loading calibration laboratory.
   Note: An exception to this procedure will be necessary for the water-cooled balances. These balances should have an additional apparent strain run following the one in Step 14. This "final apparent strain run" should be made with the balance cooling jacket in place and with the cooling jacket bellows and split-ring attached.

Moisture-proofing Procedure

Following the apparent strain run as per Step 12 in the previous section, the balance is to be coated in certain areas with a moisture barrier coating. This is to be Gagekote #8. This coating is to be applied as follows:

1. The balance should first be flushed with ENSOLV. Follow this with a flushing of pure alcohol.
2. The balance should then be heated to approximately 100° F and while the surfaces are still warm to the touch (~90° F to 100° F), the gages, jumper wires, wiring terminals, and their surrounding areas are to be covered with a brush coating of Gagekote #8. This coating should have a thickness of .005" to .007".
3. Allow this coating to air dry at least 20 minutes and apply a second coating over the first, repeating the procedure used in Step 3. Now, return to Step 13 in the previous section.

INSTALLATION TYPE 2 - The following materials and procedures are applicable for LANGLEY'S "CRYOGENIC" WIND TUNNEL BALANCES operating in the temperature range of -275° F to 150° F. Apparent strain corrections are made for the temperature range of -270° F to 140° F.

Gaging Materials (all materials that are an integral part of the balance)

1. Gage type: to be designated by design engineer, typically type: C-891113-B (Micro-Measurements)
2. Adhesive type for Gaging: M-BOND 610 (Micro-Measurements); Adhesive type for Platinum Resistance Thermometers (PRT's): EA-934 (Hysol)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of balance determines which size(s) are to be used
4. Insulation Pads for Apparent Strain Correction Wire, type: Kapton, 1 mil thick, etched on one side, length and width to be dictated by areas where pads will be placed
5. Gage-to-Terminal Jumper Wire: AWG#40 silver-clad copper
6. Apparent Strain Correction Wire (when required) type: AWG#40 silver-clad copper
7. Axial Differential Compensation Sensors (when required) type: nickel/alloy 99 (Driver-Harris)
8. Intrabridge and Interbridge Wire: AWG#30(7-38), or AWG#32(7-40) consisting of 7 strands of silver-clad copper wire with teflon insulation; balance design and size will determine wire size(s) to be utilized
9. Exit Lead Wires (when required): AWG#30(7-38) silver-clad copper wire with teflon insulation, length to be determined by design engineer
10. Solder type: 361A (Micro-Measurements)
11. PRT's type: to be designated by design engineer, typically type: EL-700T (HY-CAL)
12. Connector in Balance sting: type will be determined by the balance design specifications
13. Gaseous Nitrogen Balance Sting Purge Fitting type: Stainless Steel with Teflon o-ring
14. Thread Locking Adhesive for Sting Connector screws and Purge Fitting, type: Loctite 222
15. Sealant Between Connector and Sting, type: RTV-3140 (Dow-Corning)
16. Convection Shield, type: TFE teflon; this must be custom sized to fit the balance

Surface Preparation for Gaging

1. Degrease the entire balance. This is currently accomplished with a vapor degreasing solvent rinse type: ENSOLV (Envirotech, International).
2. Perform microscopic examination of balance looking for flaws in surface, cracked beams, sharp edges, etc.

3. Rinse balance with pure alcohol.
4. Mask appropriate areas of balance for micro-sandblasting operation.
5. Micro-sandblast areas to be gaged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the ENSOLV and alcohol rinse operations. Installation of the gages should begin immediately following this step.

Installation of the Gages

NOTE: Gages to be installed on cryogenic balances must first be "matched" for apparent strain considerations. A FSIS Memorandum to Technical Files, "Matching Cryogenic Strain Gages", dated April 18, 1994, details the procedure to be utilized for matching strain gages for cryogenic balances. This technical memorandum will be furnished with this document, at the end of the text, as Addendum #1. All strain gages to be applied to NASA Langley cryogenic balances must first be "matched" using the referenced technical memorandum.

1. At this point, the matched gages have been cleaned, cataloged, and placed in their respective pockets in a custom gage organizer. The pretrimmed wiring terminals and insulation pads for the gages should now be cleaned with pure alcohol, dried, and made ready for installation.
2. Apply a coat of M-610 to the underside of the gages, terminals, and pads to be installed as well as a coat to the appropriate balance surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature.
4. Place the gages, terminals, and pads on the balance surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages, terminals, and pads are located.
6. Apply a constant and uniform pressure of 60 psi to the rubber pads using an appropriate clamping device.
7. Place the balance in a temperature chamber and slowly raise the temperature of the balance to 340°F. This heating rate should be approximately 6°F/minute.
8. Hold the balance at this temperature for one hour, then, cool the balance.
9. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installations for accuracy of gage positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gage on the balance is typically +/-.005" of the designated location as per the balance strain gage drawing unless otherwise stated.
   NOTE: The Kapton backing and wiring terminals for the "axial" differential compensation sensors can be installed during one of the gage installation cycles using typical balance gaging techniques.
10. More than one cure cycle will be required to complete all gage installations on the balance. Therefore, the gage areas still requiring gages should be micro-sandblasted again, prior to each gaging operation, repeating the surface preparation steps previously outlined.
11. To post cure the gage installations, slowly raise the temperature at the same rate utilized for the gage installations until a balance temperature of 340°F is reached. Hold the balance at that temperature for two hours. Cool the balance and repeat the inspection of the gages.

Wiring the Balance

NOTE: Because of the considerable variation in balance design and size it is not possible to itemize and detail a standard wiring procedure for all Langley cryogenic balances. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots.

NOTE: Prior to commencing the wiring operations, mask each gage and lightly micro-sandblast the areas surrounding the gages and terminals. This will help promote a better bond between the moisture-barrier coating and the balance surfaces.

2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these balances should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All strain gage wiring for balances should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be >10K Meg ohms.
7. All intrabridge (between gages) and interbridge (between bridges) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires should be of equal resistance and length.
9. All intrabridge wires should be snug against the balance surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the balance. When wiring a balance designed for light loads, care must be exercised in preventing the wires from carrying any part of the force being applied to the measuring beams. (Later, when applying the moisture-proofing, do not allow it to bond the wiring to the load carrying beams).
10. Wire routing should be preplanned with no wiring routed over the strain gage active grids or the gage jumpers.
11. When axial differential compensation is required, wiring from the axial gages out to the differential compensating sensors should be done at this time. Shorting jumpers should be installed at the wiring terminals for each sensor so that the sensors are not part of the axial component circuit during the initial apparent strain run.
12. When all wiring, including PRT's, is completed the balance should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the balance components to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be >10K Megohms. This measurement should be made with an appropriate leakage to ground tester; a high resistance meter generating 15 volts DC potential @ 20Megohms is recommended.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the balance when in service. For each component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit. The zeros should be within +/-.050mV/V of the calculated zero. This agreement may be harder to achieve on smaller balances where lightly loaded beams and small intrabridge wiring can affect the calculated number.
3. The tolerance allowable for the recorded electrical zeros is typically quoted on the strain gaging drawing.
   NOTE: Typically, the initial zeros on all components fall within +/-.4mV/V. When an initial zero is greater than this, investigative efforts should be undertaken to determine the reason for the unbalance.
4. Mechanically shunt each gage within a bridge while observing the electrical zero in order to verify the bridge integrity. Refrain from using sharp-pointed probes for the shunting operation due to the

fact that such a tool would leave indentations in the solder joints.

5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the balance.

Elevated Temperature Soak Cycle

Prior to conducting apparent strain runs a temperature soak of the completely wired balance is to be performed at a temperature of 200° F for 4 hours. After the balance is cooled, check the zeros against the zeros recorded in Step 3 above. A large change in zero in a given component (>.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change.

Apparent Strain Correction

Once the elevated temperature soak cycle is completed, proceed with the apparent strain correction as follows:

1. Place the balance in the temperature chamber horizontally, in the -Normal Force up position, supported at the non-metric end only. The convection shield, if required, should be in place on the balance for all apparent strain runs.
2. The calibration load fixture should be installed on the balance as it would be for the loads calibration.
3. If the temperature chamber utilizes fans to produce air circulation, the front end of the balance should be facing in the direction of the air flow.
4. Connect the balance to the data acquisition system as per the "Balance Set Up" portion of the systems' apparent strain program. Allow this set-up to stabilize until the three PRT's used for monitoring (typically, they are #TFB1,#TMB1,#TRB1) read within 3° F of each other. The starting temperature for the apparent strain runs should be between 70° F and 75° F. Commence recording data.
5. When all zeros are stable, i.e., drift rate is <.005mV/5VDC/3 minutes, commence the gas nitrogen purging. The rate for this nitrogen purge is typically 4.5SLPM.
   NOTE: This gas nitrogen purging is to be used for <u>all</u> of the apparent strain runs with Langley's cryogenic balances.
6. Now, wait for the zeros to re-stabilize as per the drift rate in Step 5.
7. Once the zeros are stable, start the "temperature versus output" apparent strain run by setting the temperature chamber controller at -280° F and commencing the cool-down of the chamber.
8. Cool the balance until a stable temperature within five degrees of the -270° F target temperature can be maintained with the three monitoring PRT's. All three PRT's must read within 3° F of each other. Maintain the balance in this state until all components are stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
9. Following stabilization of all zeros at the -270° F target temperature, heat the balance to room temperature adjusting the temperature chamber controller as necessary to bring the balance back to room temperature.
10. <u>It is important</u> that the balance temperature be observed during the heat-up phase of the run and that <u>the power supply be turned off when the balance temperature reaches 0° F.</u>
11. On a worksheet, record the output of each component at -270° F with respect to the initial room temperature zero.
12. For each component requiring reduction of its apparent strain, add an appropriate amount of copper wire to the appropriate arm of the bridge circuit to nullify the apparent strain of the bridge. The tolerance allowed for apparent strain is provided on the gaging drawing. This is typically +/-.005mV/V/Δ100° F.

13.Make another apparent strain run as per Steps 1 through 10.
14.At this time, make the initial resistance adjustment of the Axial differential compensation sensors as the magnitude of "loop error data" dictates.
15.Make another apparent strain run as per Steps 1 through 10. It may be necessary to adjust the axial differential compensation sensors resistances again to achieve the desired reduction in the loop error data.
16.After verifying that the apparent strains, non-linearity, and loop data meet the design engineers' specifications, coat the balance with the M-COAT B moisture-barrier as follows.

<u>Moisture-Proofing Procedure</u>

1. Using the microscopic visual inspection system, record the appearance of the strain-gaged balance.
2. Flush the balance with ENSOLV. Follow this with a flushing of pure Alcohol.
3. Record, on a worksheet, the electrical zeros prior to applying the M-COAT B. Also, record the leakage to ground resistance (this should be >10K Megohms).
4. Apply the first coat of M-COAT B over all exposed solder joints and uninsulated wiring. Do not allow the coating to cover any portion of the active grids of the strain gages. The cured coating should be approximately .002" to .003" thick. The coating should only be applied when the ambient temperature of the balance is at least 75° F and the relative humidity in the laboratory is less than 40 percent.
5. Allow this first coat to air dry for two hours in the lab environment as described in Step 4.
6. Apply the second coat of M-COAT B over the first coat making certain that the second coat completely encapsulates the first. Use the procedure described in Step 4 as a guide.
7. Allow this second coat to air dry for two hours in the lab environment as described in Step 4.
8. Record, on the worksheet, the new electrical zeros with the M-COAT B in place. These zeros should be within .050mV/5VDC of the zeros recorded in Step 3. Also, record the leakage to ground resistance. This should still be >10K Megohms.

<u>Final Apparent Strain Verification Runs</u>

NOTE: Following application of the moisture-barrier coating, the balance should be subjected to a series of temperature excursions both hot and cold to verify that the madnitude and repeatability of apparent strain, non-linearity, and loop data that may still be present, are within the design engineer's specifications for this particular balance.

1. Set up the balance in the chamber as was described in Step 1 through Step 6 of the section titled <u>"Apparent Strain Correction"</u>.
2. Now, once the zeros are stable (as per Step 6 of the <u>Apparent Strain Correction</u>), start the "temperature versus output" apparent strain run by setting the temperature controller at 150° F and commencing the heating of the chamber.
3. Heat the balance until a stable temperature within five degrees of the 150° F target temperature can be maintained with the three monitoring PRT's. All three PRT's must read within 3° F of each other. Maintain the balance in this state until all components are stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
4. Following stabilization of all zeros at the 150° F target temperature, reset the chamber temperature controller to -280° F and cool the balance.
5. Cool the balance until a stable temperature within five degrees of the -270° F target temperature can be maintained with the three monitoring PRT's. All three PRT's must read within 3° F of each other. Maintain the balance in this state until all components are stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
6. Following stabilization of all zeros at the -270° F target temperature, heat the balance to room

temperature adjusting the temperature chamber controller as necessary to bring the balance back to room temperature.
NOTE: Excitation voltage should be kept on the bridges during the return to room temperature. However, the temperature should be visually monitored and if any spurious strain gage data are observed between 0°F and room temperature, the power to the bridges should be shut off.

7. Next, repeat the operations that were performed in Step 2 through Step 6.
8. Now, perform one more apparent strain verification run as was done in Step 7.
   NOTE: The purpose of these runs is to verify the repeatability of the apparent strain run data. If repeatability cannot be obtained with the second and third runs of this series of runs, the reason(s) should be investigated and corrected. Consecutive runs, with repeatable data, are essential prior to releasing the balance for load calibration.

Final Checks Prior to Sending Balance to Calibration Lab

1. Record final zeros.
2. Remove the teflon convection shield and conduct a "leakage to ground resistance" wet brush test. Measure and record the leakage to ground resistance of the bridges by flooding the gage areas and solder joint areas with regular tap water using a soft artist brush to carry the water to the respective areas.
3. Conduct a "water effects on signal" wet brush test. Measure the spurious signals, if there are any, on each bridge as tap water is applied as per Step 2. No spurious signal should exceed .075mV/8VDC excitation voltage.
   NOTE: The excitation voltage of 8 VDC simply provides a means of subjecting the balance to a more harsh test environment than it will see in operation. This level of excitation voltage is to be used only for this one test.
4. Using the microscopic visual inspection system, record the appearance of the strain-gaged balance.
5. Reinstall the convection shield and send the balance to the balance design engineer.

FINAL NOTES:
With the current focused effort directed toward improving reliability and accuracy for the NTF-type balances, it is reasonable to expect continuing changes in the methods and materials that are currently being used for these balances. It is imperative that all phases of the strain gaging tasks for these balances be reviewed and agreed to by the balance design engineer.

Also, the balances' historical log book, initiated by the balance design engineer, should be maintained with each new cryogenic balance. The strain gage technician should add detailed notes of any deviations from the balance drawings, gaging specifications, problems encountered during the gaging, and related discussions with the design engineer. This log book should be returned to the balance design engineer upon completion of the gaging effort.

APPLICATION CLASS II - GAGE INSTALLATION PROCEDURES FOR ALL LANGLEY DESIGNED TRANSDUCERS OTHER THAN BALANCES

INSTALLATION TYPE 1 - The following materials and procedures are applicable for all LANGLEY DESIGNED TRANSDUCERS operating in the temperature range of 0°F to 200°F. Apparent strain corrections are made for the temperature range of 80°F to 180°F.

Gaging Materials (all materials that are an integral part of the transducer)

1. Gage type: to be designated by design engineer, typically type: C-891113-A (Micro-Measurements)
2. Adhesive type for gaging: M-BOND 610 (Micro-Measurements); adhesive type for PRT's when required: EA-934 (Hysol)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of the transducer determines which size(s) are to be used
4. Insulation Pads for Apparent Strain and Zero Correction Wires, when required, type: Kapton, 1-mil, etched
5. Gage-to-Terminal Jumper Wire: AWG#40 silver-clad copper
6. Apparent Strain Correction Wire (when required) type: nickel; size determined by amount required for correction
7. Zero Offset Correction Wire (when required) type: Manganin (Driver-Harris); size determined by amount required for correction
8. Intrabridge and Interbridge Wire: AWG#30(7-38), #32(7-40), or #36(7-44) consisting of 7 strands of silver-clad copper wire with teflon insulation; size selected will be determined by transducer size. Some small transducers will require single conductor solid copper, AWG#40 or AWG#42.
9. Exit Lead Wires (when required): Size and length determined by design engineer
10. Transducer Connector: to be designated by design engineer, user facility dependant
11. Solder type: 361A (Micro-Measurements)
12. Thermocouples (when required) type: "J" size AWG#36, w/teflon insulation
13. Platinum Resistance Thermometers (PRT's)-when required-type: EL-700T (HY-CAL)
14. Protective Gage Coating type: Gagekote #8 (JP Technologies)
15. Protective Sleeving over Exit Lead Wires (when required): nylon or fiberglass, as per the design engineer

Surface Preparation for Gaging

1. Degrease the entire transducer. This is currently accomplished with a vapor degreasing solvent rinse type: ENSOLV (Envirotech, International).
2. Perform microscopic examination of the transdOucer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse the transducer with pure alcohol.
4. Mask appropriate areas of the transducer for micro-sandblasting operation.
5. Micro-sandblast the areas to be gaged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the ENSOLV and alcohol rinse operations. Installation of the gages should begin immediately following this step.

Installation of the Gages

1. Gages and pretrimmed wiring terminals should be cleaned with pure alcohol, dried, and placed on a clean glass plate, inverted and ready for installation.
2. Apply a coat of M-610 to the underside of the gages, terminals, and insulation pads (when used) to be installed, as well as a coat to the appropriate transducer surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature.
4. Place the gages, terminals, and pads on the transducer surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages and terminals are located.
6. Apply a constant and uniform pressure of 60 psi to the rubber pads using an appropriate clamping device.
7. Place the transducer in a temperature chamber and slowly raise the temperature of the transducer to 340° F. This heating rate should be approximately 6° F/minute.
8. Hold the transducer at this temperature for one hour, then, cool the transducer.
9. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installations for accuracy of gage positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gage on the transducer is typically +/-.005" of the stated location as per the transducer strain gage drawing unless otherwise stated.
10. When more than one cure cycle will be required to complete all gage installations on the transducer, the gage areas still requiring gages should be micro-sandblasted again, prior to each gaging operation, repeating the surface preparation steps previously outlined.
11. To post cure the gage installations, slowly raise the temperature at the same rate utilized for the gage installations until a transducer temperature of 340° F is reached. Hold the transducer at that temperature for two hours. Cool the transducer and repeat the inspection of the gages.

Wiring the Transducer

NOTE: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley transducers. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All strain gage wiring for transducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be >10K Meg ohms.
7. All intrabridge and interbridge wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires should be of equal resistance and length.
9. All intrabridge wires should be snug against the transducer beam surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer designed for light loads, care must be exercised in preventing the wires from carrying any part of the force being applied to the measuring beams. (Later, when applying the

moisture-proofing, do not allow it to bond the wiring to the load carrying beams).
10. Wire routing should be preplanned with no wiring routed over the strain gage active grids or the gage jumpers.
11. When all wiring is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer component(s) to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be >10K Megohms. This measurement should be made with an appropriate leakage to ground tester; a high resistance meter generating 15 volts potential @ 20Megohms is recommended.
2. Record the bridge electrical zero(s). Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit. The zeros should be within +/-.050mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small intrabridge wiring can affect the calculated number.
3. The tolerance allowable for the recorded electrical zeros for all components is quoted on the transducer strain gage drawing. The typical allowance is +/-.4mV/V.
4. Mechanically shunt each gage within a bridge while observing the electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycle

Prior to conducting apparent strain runs a temperature soak of the completely wired transducer is to be performed at a temperature of 200°F for 4 hours. After the transducer cools, check the zeros against the zeros recorded in Step 2 above. A large change in zero in a given component (>.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change.

Apparent Strain Correction

Once the elevated temperature soak cycle is completed, proceed with the apparent strain correction as follows:

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that no direct air flows can reach the transducer.
3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has its own thermocouple or PRT, it should be utilized.
4. Connect the transducer to the data acquisition system (bridge voltage is to be the same as that which will be used for the complete transducer load calibration). Allow this set-up to stabilize for several minutes.
5. Start the "temperature versus output" recording with the temperature chamber air flow on and the chamber temperature controller set at 80°F.
6. Continue recording the room temperature output(s) until all component zeros are stabilized, i.e., not

changing more than .005mV/5VDC/5minutes. The temperature on the monitor thermocouple (or PRT) should also be stabilized.
NOTE: The monitoring thermocouple (or PRT) on the transducer should be brought to within +/- 2°F of the required 80°F prior to commencing the temperature excursion up to 180°F.

7. Turn the temperature controller setting to 180°F and heat the transducer until a stable temperature within five degrees of the 180°F target temperature can be maintained. The monitoring thermocouple or PRT on the transducer is to be used as the determining factor for this step. The heating rate should not exceed 6°F/minute.
8. Allow the transducer to soak at the elevated stabilized temperature for at least fifteen minutes. For larger transducers, more time may be required to stabilize the transducer zero(s) at the required elevated temperature.
9. Following stabilization of all zeros at the 180°F target temperature, cool the transducer to room temperature adjusting the temperature chamber controller as necessary to bring the actual transducer temperature to the same temperature (within +/- 2°F) that was recorded in Step 6.
10. On a worksheet, use the recorded apparent strain run to record the output of each component at 180°F with respect to the 'return to room temperature' zero.
11. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm of the bridge circuit to nullify the apparent strain of the bridge. The tolerance allowed for apparent strain is provided on the transducer gaging drawing. This is typically +/-.005mV/V/Δt100°F.
12. Make another apparent strain run as per Steps 1 through 11.
13. After verifying that the apparent strain outputs are within the design engineer's specifications for all components, install the moisture-barrier protective coating (per procedure in next section) over the gages, solder joints, and wires as appropriate and place the transducer back in the temperature chamber. Conduct an initial apparent strain check run with the protective coating in place.
14. Make another apparent strain run for the transducer as per Steps 1 through 11. This run is made in order to confirm repeatability for consecutive apparent strain runs. All respective components should be repeatable (with respect to the previous run) within +/-.003mV/V throughout the entire temperature excursion. Once this specification is met, that run becomes the final apparent strain run. Following a final microscopic examination the transducer should be ready to be forwarded to the loading calibration laboratory.

Moisture-proofing Procedure

Following the apparent strain run as per Step 12 in the previous section, the transducer is to be coated in certain areas with a moisture barrier coating. This is to be Gagekote #8. This coating is to be applied as follows:

1. The transducer should first be flushed with ENSOLV. Follow this with a flushing of pure alcohol.
2. The transducer should then be heated to approximately 100°F and while the surfaces are still warm to the touch (~90°F to 100°F), the gages, jumper wires, wiring terminals, and their surrounding areas are to be covered with a brush coating of Gagekote #8. This coating should have a thickness of .005" to .007".
3. Allow this coating to air dry at least 20 minutes and apply a second coating over the first, repeating the procedure used in Step 3. Now, return to Step 13 in the previous section.

INSTALLATION TYPE 2 - The following materials and procedures are applicable for LANGLEY DESIGNED CRYOGENIC TRANSDUCERS operating in the temperature range of -275° F to 150° F. Apparent strain corrections are made for the temperature range of -270° F to 140° F.

Gaging Materials (all materials that are an integral part of the transducer

1. Gage type: to be designated by design engineer, typically type: C-891113-B (Micro-Measurements)
2. Adhesive type for Gaging: M-BOND 610 (Micro-Measurements); Adhesive type for Platinum Resistance Thermometer (PRT) when used: EA-934 (Hysol)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of transducer determines which size(s) are to be used
4. Insulation Pads for Apparent Strain Correction Wire, type: Kapton, 1 mil thick, etched on one side, length and width to be dictated by areas where pads will be placed
5. Gage-to-Terminal Jumper Wire: AWG#40 silver-clad copper
6. Apparent Strain Correction Wire (when required) type: AWG#40 silver-clad copper
7. Intrabridge and Interbridge Wire: AWG#30(7-38), or AWG#32(7-40) consisting of 7 strands of silver-clad copper wire with teflon insulation; transducer design and size will determine wire size(s) to be utilized
8. Thermocouple, when used, type: "T", usually size AWG #30, with teflon insulation
9. PRT, when used, type: to be designated by design engineer, typically type: EL-700T (HY-CAL)
10. Exit Lead Wires (when required): AWG#30(7-38) silver-clad copper wire with teflon insulation, length to be determined by transducer design engineer
11. Solder type: 361A (Micro-Measurements)
12. Transducer Connector (when used) type: will be determined by the transducer design specifications
13. Thread Locking Adhesive for Connector screws (when used) type: Loctite 222
14. Sealant Between Connector and transducer housing (when used) type: RTV-3140 (Dow-Corning)

Surface Preparation for Gaging

1. Degrease the entire transducer. This is currently accomplished with a vapor degreasing solvent rinse type: ENSOLV (Envirotech, International).
2. Perform microscopic examination of transducer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse transducer with pure alcohol.
4. Mask appropriate areas of transducer for micro-sandblasting operation.
5. Micro-sandblast areas to be gaged using 50 micron Al_2O_3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the ENSOLV and alcohol rinse operations. Installation of the gages should begin immediately following this step.

Installation of the Gages

NOTE: Gages to be installed on cryogenic balances must first be "matched" for apparent strain considerations. A FSIS Memorandum to Technical Files, "Matching Cryogenic Strain Gages", dated April 18, 1994, details the procedure to be utilized for matching strain gages for cryogenic balances. This technical memorandum will be furnished with this document, at the end of the text, as Addendum #1. All strain gages to be applied to NASA Langley cryogenic balances must first be "matched" using the referenced technical memorandum.

1. At this point, the matched gages have been cleaned, cataloged, and placed in their respective pockets in a custom gage organizer. The pretrimmed wiring terminals and insulation pads for the

gages should now be cleaned with pure alcohol, dried, made ready for installation.

2. Apply a coat of M-610 to the underside of the gages, terminals, and pads to be installed as well as a coat to the appropriate transducer surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature.
4. Place the gages, terminals, and pads on the transducer surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages, terminals, and pads are located.
6. Apply a constant and uniform pressure of 60 psi to the rubber pads using an appropriate clamping device.
7. Place the transducer in a temperature chamber and slowly raise the temperature of the transducer to 340°F. This heating rate should be approximately 6°F/minute.
8. Hold the transducer at this temperature for one hour, then, cool the transducer to room temperature.
9. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installations for accuracy of gage positioning and alignment, glue-line voids, or foreign matter. The tolerance for location of the gage on the transducer is typically +/-.005" of the stated location as per the transducer strain gage drawing unless otherwise stated.
10. When more than one cure cycle is required to complete all gage installations on the transducer, the gage areas still requiring gages should be micro-sandblasted again, prior to each gaging operation, repeating the surface preparation steps previously outlined.
11. To post cure the gage installations, slowly raise the temperature at the same rate utilized for the gage installations until a temperature of 340°F, on the transducer, is reached. Hold the transducer at that temperature for two hours. Cool the transducer and repeat the inspection of the gages.

<u>Wiring the Transducer</u>

NOTE: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley cryogenic transducers. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots. NOTE: Prior to commencing the wiring operations, mask each gage and lightly micro-sandblast the areas surrounding the gages and terminals. This will help promote a better bond between the moisture-barrier coating and the transducer surfaces.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All strain gage wiring for transducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be >10K Meg ohms.
7. All intrabridge and interbridge wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires should be of equal resistance and length.
9. All intrabridge wires should be snug against the transducer surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer

designed for light loads, care must be exercised in preventing the wires from carrying any part of the force being applied to the measuring beams. (Later, when applying the moisture-proofing, do not allow it to bond the wiring to the load carrying beams).

10. Wire routing should be preplanned with no wiring routed over the strain gage active grids or the gage jumpers.
11. When all wiring, including thermocouples and PRT's (when used), is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer component(s) to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be >10K Megohms. This measurement should be made with an appropriate leakage to ground tester; a high resistance meter generating 15 volts DC potential @ 20Megohms is recommended.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit. The zeros should be within +/-.050mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small intrabridge wiring can affect the calculated number.
3. The tolerance allowable for the recorded electrical zeros is quoted on the strain gaging drawing. The typical allowance is +/-.4mV/V.
4. Mechanically shunt each gage within a bridge while observing the electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycle

Prior to conducting apparent strain runs a temperature soak of the completely wired transducer is to be performed at a temperature of 200°F for 4 hours. After the transducer cools, check the zero(s) against the zeros recorded in Step 2 above. A large change in zero in a given component (>.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change.

Apparent Strain Correction

Once the elevated temperature soak cycle is completed, proceed with the apparent strain correction as follows:

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that no direct air flows can reach the transducer.
3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has its own thermocouple or PRT, it should be utilized.
4. Hook-up the transducer to the data acquisition system (bridge voltage is to be the same as that which will be used for the complete transducer load calibration). Allow this set-up to stabilize for several minutes.
5. When the zero(s) is stable, i.e., drift rate is <.005mV/5VDC/3 minutes, commence the gas nitrogen

purging. The design of the transducer will determine the manner in which purging is accomplished for the gage areas of the transducer. The rate for this nitrogen purge is typically 4.5SLPM. NOTE: This gas nitrogen purging is to be used for all of the apparent strain runs with Langley designed transducers..

6. Now, wait for the zero(s) to re-stabilize as per the drift rate in Step 5.
7. Once the zero is stable, start the "temperature versus output" apparent strain run by setting the temperature chamber controller at -280° F and commencing the cool-down of the chamber.
8. Cool the transducer until a stable temperature within five degrees of the -270° F target temperature can be maintained with the monitoring thermocouple or PRT. Maintain the transducer in this state until the zero(s) is stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
9. Following stabilization of all zeros at the -270° F target temperature, heat the transducer to room temperature adjusting the temperature chamber controller as necessary to bring the transducer back to room temperature.
10. It is important that the transducer temperature be observed during the heat-up phase of the run and that the power supply be turned off when the transducer temperature reaches 0° F.
11. On a worksheet, record the output of each component at -270° F with respect to the initial room temperature zero.
12. For each component requiring reduction of its apparent strain, add an appropriate amount of copper wire to the necessary arm of the bridge circuit to nullify the apparent strain of the bridge. The tolerance allowed for apparent strain is provided on the gaging drawing. This is typically +/-.005mV/V/Δ100° F.
13. Make another apparent strain run as per Steps 1 through 10.
14. After verifying that the apparent strains, non-linearity, and repeatability meet the design engineers' specifications, coat the transducer with the M-COAT B moisture-barrier as follows.

Moisture-Proofing Procedure

1. Using the microscopic visual inspection system, record the appearance of the strain-gaged transducer.
2. Flush the transducer with ENSOLV. Follow this with a flushing of pure Alcohol.
3. Record, on a worksheet, the electrical zero(s) prior to applying the M-COAT B. Also, record the leakage to ground resistance (this should be >10K Megohms).
4. Apply the first coat of M-COAT B over all exposed solder joints and uninsulated wiring. Do not allow the coating to cover any portion of the active grids of the strain gages. The cured coating should be approximately .002" to .003" thick. The coating should only be applied when the ambient temperature of the balance is at least 75° F and the relative humidity in the laboratory is less than 40 percent.
5. Allow this first coat to air dry for two hours in the lab environment as described in Step 4.
6. Apply the second coat of M-COAT B over the first coat. Apply it as was described in Step 4.
7. Allow this second coat to air dry for two hours in the lab environment as described in Step 4.
8. Record, on the worksheet, the new electrical zero with the M-COAT B in place. This zero should be within .050mV/5VDC of the zeros recorded in Step 3. Also, record the leakage to ground resistance. This should still be >10K Megohms.

Final Apparent Strain Verification Runs

NOTE: Following application of the moisture-barrier coating, the transducer should be subjected to a series of temperature excursions both hot and cold to verify that the madnitude and repeatability of apparent strain, non-linearity, and loop data that may still be present, are within the design engineer's specifications for this particular transducer.

1. Set up the transducer in the chamber as was described in Step 1 through Step 6 of the section titled "Apparent Strain Correction."
2. Now, once the zero(s) is stable (as per Step 6 of the "Apparent Strain Correction"), start the "temperature versus output" apparent strain run by setting the temperature controller at 150° F and commencing the heat-up of the chamber.
3. Heat the transducer until a stable temperature within five degrees of the 150° F target temperature can be maintained with the monitoring thermocouple or PRT. Maintain the transducer in this state until the component(s) is stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
4. Following stabilization of all zeros at the 150° F target temperature, reset the chamber temperature controller to -280° F and cool the transducer.
5. Cool the transducer until a stable temperature within five degrees of the -270° F target temperature can be maintained with the monitoring thermocouple or PRT. Maintain the transducer in this state until all components are stable, i.e., drift rate is <.005mV/5VDC/3 minutes.
6. Following stabilization of all zeros at the -270° F target temperature, heat the transducer to room temperature adjusting the temperature chamber controller as necessary to bring the transducer back to room temperature.
   NOTE: Excitation voltage should be kept on the bridges during the return to room temperature. However, the temperature should be visually monitored and if any spurious strain gage data are observed between 0° F and room temperature, the power to the bridges should be shut off.
7. Next, repeat the operations that were performed in Step 2 through Step 6.
8. Now, perform one more apparent strain verification run as was done in Step 7.
   NOTE: The purpose of these runs is to verify the repeatability of the apparent strain run data. If repeatability cannot be obtained with the second and third runs of this series of runs, the reason(s) should be investigated and corrected. Consecutive runs, with repeatable data, are essential prior to releasing the transducer for load calibration.

Final Checks Prior to Sending the Transducer to the Calibration Lab

1. Record final zeros.
2. Conduct a "leakage to ground resistance" wet brush test. Measure and record the leakage to ground resistance of the bridge(s) by flooding the gage areas and solder joint areas with regular tap water using a soft artist brush to carry the water to the respective areas.
3. Conduct a "water effects on signal" wet brush test. Measure the spurious signals, if there are any, on each bridge as tap water is applied as per Step 2. No spurious signal should exceed .075mV/8VDC excitation voltage.
   NOTE: The excitation voltage of 8 VDC simply provides a means of subjecting the transducer to a more harsh test environment than it will see in operation. This level of excitation voltage is to be used only for this one test.
4. Using the microscopic visual inspection system, record the appearance of the strain-gaged transducer.
5. Finally, send the transducer to the transducer design engineer.

INSTALLATION TYPE 3 - The following materials and procedures are applicable for LANGLEY DESIGNED HIGH-TEMPERATURE TRANSDUCERS operating in the temperature range of 200°F to 450°F. Apparent strain corrections are made for the temperature range of 80°F to the maximum operating temperature of the transducer.

Gaging Materials (all materials that are an integral part of the transducer)

1. Gage type: to be designated by design engineer, typically type: J5K-06-S104P-350/DP
2. Adhesive type: M-BOND 450 (Micro-Measurements)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of transducer load beams determines which size(s) are to be used
4. Gage-to-Terminal Jumper Wire: AWG#40 silver-clad copper
5. Apparent Strain Correction Wire (when required) type: nickel; size determined by amount required for correction
6. Zero Offset Correction Wire (when required) type: Manganin (Driver-Harris); size determined by amount required for correction
7. Intrabridge and Interbridge (when required) Wire: AWG#30(7-38), #32(7-40), or #36(7-44) consisting of 7 strands of silver-clad copper wire with teflon insulation; size selected will be determined by transducer size. Some small transducers will require single conductor solid copper, AWG#40 or AWG#42.
8. Exit Lead Wires: Size and length specified by design engineer
9. Solder type: 570-28R (Micro-Measurements)
10. Thermocouple(s) (when required) typically type: "J" size AWG#36, w/teflon insulation
11. Platinum Resistance Thermometer (PRT) (when required) type: EL-700T (HY-CAL)
12. Protective Gage Coating type: 3140 RTV (Micro-Measurements)
13. Protective Sleeving over Exit Lead Wires: fiberglass or polymer as per design engineer

Surface Preparation for Gaging

1. Degrease the entire transducer. This is currently accomplished with a vapor degreasing solvent rinse type: ENSOLV (Envirotech, International).
2. Perform microscopic examination of transducer looking for flaws in surface, cracked beams, sharp edges, etc.
3. Rinse transducer with pure alcohol.
4. Mask appropriate areas of transducer for micro-sandblasting operation.
5. Micro-sandblast areas to be gaged using 50 micron Al2O3 abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the ENSOLV and alcohol rinse operations. Installation of the gages should begin immediately following this step.

Installation of the Gages

All gages are to be installed as per "Instructions for the Application of Micro-Measurements M-Bond 450 Adhesive", published by Measurements Group, Inc. in 1990. This is included as Addendum #2 at the end of the text. It should be noted that Step 4 of that document may require modification to include the use of CHR, type C teflon tape in place of the MJG-2 Mylar tape. Also, it is recommended that the clamping pressure be set at 50 psi and the post cure temperature be set at 50°F higher than the maximum operating temperature for the transducer being instrumented.

Wiring the Transducer

NOTE: Because of the considerable variation in transducer design and size it is not possible to itemize and detail a standard wiring procedure for all Langley cryogenic transducers. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots. NOTE: Prior to commencing the wiring operations, mask each gage and lightly micro-sandblast the areas surrounding the gages and terminals. This will help promote a better bond between the moisture-barrier coating and the transducer surfaces.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these transducers should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage to two decimal places at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All strain gage wiring for transducers should be subjected to an insulation resistance test by submerging the wire in regular tap water and measuring the leakage to ground resistance. This resistance should be >10K Meg ohms.
7. All intrabridge and interbridge wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires should be of equal resistance and length.
9. All intrabridge wires should be snug against the transducer surfaces along the entire length of the wire. Do not allow any wiring to span open areas within the transducer. When wiring a transducer designed for light loads, care must be exercised in preventing the wires from carrying any part of the force being applied to the measuring beams. (Later, when applying the moisture-proofing, do not allow it to bond the wiring to the load carrying beams).
10. Wire routing should be preplanned with no wiring routed over the strain gage active grids or the gage jumpers.
11. When all wiring, including thermocouples and PRT's (when used), is completed the transducer should be cleaned to remove all soldering residues and other foreign matter.

Initial Electrical Checks

1. Check the transducer component(s) to verify that there is no significant resistance leakage to ground. The leakage to ground resistance should be >10K Megohms. This measurement should be made with an appropriate leakage to ground tester; a high resistance meter generating 15 volts potential @ 20Megohms is recommended.
2. Record the bridge electrical zeros. Bridge excitation voltage should be the same as that to be used for the transducer when in service. For each component, check to confirm that the zero is representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit. The zeros should be within +/-.050mV/V of the calculated zero. This agreement may be harder to achieve on smaller transducers where lightly loaded beams and small intrabridge wiring can affect the calculated number.
3. The tolerance allowable for the recorded electrical zeros is quoted on the strain gaging drawing. The typical allowance is +/-.4mV/V.
4. Mechanically shunt each gage within a bridge while observing the electrical zero in order to verify the bridge integrity.
5. When possible, hand-load each component to verify expected sensitivity. Also, check for zero shifts

as a function of loading and unloading the transducer.

Elevated Temperature Soak Cycle

Prior to conducting apparent strain runs a temperature soak of the completely wired transducer is to be performed at a temperature commensurate with the maximum operating temperature of the transducer. Hold at this temperature for 2 hours. After the transducer is cooled, check the zeros against the zeros recorded in Step 2 above. A large change in zero in a given component (>.010mV/V) indicates a potential problem and the component should be investigated further to resolve the source of the zero change.

Apparent Strain Correction

Once the elevated temperature soak cycle is completed, proceed with the apparent strain correction as follows:

1. Place the transducer in the temperature chamber in a manner that will allow the transducer load beams to expand without constraint.
2. The transducer should be covered with a non-contacting encasement uniformly constructed such that no direct air flows can reach the transducer.
3. For monitoring temperature during the run, attach a thermocouple to the transducer in an area as close to the load beam(s) as possible, using a piece of aluminum tape. If the transducer has its own thermocouple or PRT, it should be utilized.
4. Connect the transducer to the data acquisition system. Bridge voltage is to be set at that which will be used for the complete transducer load calibration. Allow this set-up to stabilize for several minutes.
5. Start the "temperature versus output" recording with the temperature chamber air flow on and the chamber temperature controller set at 80° F.
6. Continue recording the room temperature output(s) until all component zeros are stable, i.e., not changing more than .005mV/5VDC/5minutes. The temperature on the monitor thermocouple (or PRT) should also be stable.
   NOTE: The monitoring thermocouple (or PRT) on the transducer should be brought to within +/- 2° F of the required 80° F prior to commencing the temperature excursion up to the maximum operating temperature for this particular transducer.
7. Turn the temperature controller setting to the maximum operating temperature for the transducer and heat the transducer until a stable temperature within five degrees of the target temperature can be maintained reading the monitoring temperature on the transducer. The heating rate should not exceed 6° F/minute.
8. Allow the transducer to soak at the elevated stabilized temperature for at least fifteen minutes. For larger transducers, longer time may be required to stabilize the transducer zero(s) at the required elevated temperature.
9. Following stabilization of all zeros at the elevated target temperature, cool the transducer to room temperature adjusting the temperature chamber controller as necessary to bring the actual transducer temperature to the same temperature (within +/- 2° F) that was recorded in Step 6.
10. On a worksheet, use the recorded apparent strain run to record the output of each component at the elevated target temperature with respect to the 'return to room temperature' zero.
11. For each component requiring reduction of its apparent strain, add an appropriate amount of nickel wire to the necessary arm of the bridge circuit to nullify the apparent strain of the bridge. The tolerance allowed for apparent strain is provided on the transducer gaging drawing. This is typically +/-.005mV/V/Δ100° F.
12. Make another apparent strain run as per Steps 1 through 11.

13. After verifying that the apparent strain outputs are within the design engineer's specifications for all components, install the moisture-barrier protective coating (per procedure in next section) over the gages, solder joints, and wires as appropriate and place the transducer back in the temperature chamber. Conduct an initial apparent strain check run with the protective coating in place.
14. Make another apparent strain run for the transducer as per Steps 1 through 11. This run is made in order to confirm repeatability for consecutive apparent strain runs. All respective components should be repeatable within +/-.003mV/V with respect to the previous run throughout the entire temperature excursion. Once this specification is met, that run becomes the final apparent strain run. Following a final microscopic examination the transducer should be ready to be forwarded to the loading calibration laboratory.

Moisture-proofing Procedure

1. Following the apparent strain run as per Step 12 in the previous section, the transducer is to be coated in certain areas with a protective barrier coating which serves as a moisture barrier while providing a degree of protection from possible in-service abuse. This coating is to be RTV 3140.
2. The transducer should first be flushed with ENSOLV. Follow this with a flushing of pure alcohol.
3. The transducer should then be heated to approximately 100°F and while the surfaces are still warm to the touch (~80°F to 90°F), the gages, jumper wires, wiring terminals, and their surrounding areas are to be covered with a brush coating of RTV 3140. This coating should have a thickness of .025" to .035".
4. Allow this coating to air dry overnight, then, return to Steps 13 and 14 in the previous section. Following completion of Step 14, a final microscopic visual recording should be made of the transducer's strain gaged areas.

INSTALLATION TYPE 4 - The following materials and procedures are applicable for LANGLEY "SPACEFLIGHT DESIGNATED" transducers

NOTE: Detailed strain gage application procedures for "spaceflight transducers" are not included in this memorandum for the following reasons:

1. Materials to be used for spaceflight must be approved by the requesting project engineer. There are limited materials allowed depending on the particular type of test for the flight envelope. Therefore, materials cannot be readily quoted here.
2. Temperature limitations for the transducer and (or) for the gaging materials selected influence gaging procedures. Therefore, detailed gaging procedures cannot be specified here.
3. Laboratory testing of the installed gages will vary considerably depending on the flight environment. Therefore, specifed laboratory tests to be performed on installed gages cannot be quoted here.
4. Obviously, each Langley transducer designed for spaceflight considerations must have its own custom "gage application procedure".
5. The first three installation types detailed in this "APPLICATION CLASS" can be used as a guide for strain gaging spaceflight type transducers.

APPLICATION CLASS III - GAGE INSTALLATION PROCEDURES FOR CERTAIN COMPOSITE MATERIALS

NOTE: Application Class III details gaging procedures for various composite articles including composite panels, fuselage test items, and laboratory type test coupons. This class does not include gaging procedures for high-temperature composites with free-filament gages.

INSTALLATION TYPE 1 - The following materials and procedures are applicable for gaging GRAPHITE/EPOXY (GR/EP) COMPOSITES for structural analysis or materials properties testing at ROOM TEMPERATURE.

Gaging Materials (all materials that are an integral part of the strain gaged composite)

1. Gage type: to be designated by test engineer, typically CEA series (Micro-Measurements)
2. Adhesive type: M-Bond GA-2 or M-Bond 200 (Micro-Measurements), See "Installation of the Gages" note on the next page
3. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor flat ribbon, size AWG#30, stranded, silver-plated copper with a vinyl insulation over each conductor
4. Solder type: 361-A (Micro-Measurements)
5. Protective Gage Coating type: M-Coat A (Micro-Measurements)

Surface Preparation for Gaging

1. Perform general degreasing and cleaning of the surface(s) to be gaged using ENSOLV and 200 proof alcohol.
2. Visually examine (microscopic when possible) the areas to be gaged checking for cracks, broken fibers, voids, etc.
3. Mask areas to be gaged and micro-sandblast using 50 micron Al2O3 abrasive powder or hand-sand using 220 grit silicon-carbide abrasive paper.
4. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
5. Clean the surface again with 200 proof alcohol.
   NOTE: Because uncoated graphite/epoxy composite surfaces are typically quite porous, and, at times, too rough for gaging, a basecoat should be applied in the areas to be gaged. The following steps work well.
6. Apply a liberal coat of GA-2 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
7. On flat surfaces this basecoat can be left to dry as is. On surfaces where sag or runoff is a concern, place a teflon film pad over the basecoat, install a vacuum applicator pad over the teflon, and apply vacuum to the applicator pad.
8. Cure the test article for 4 hours at a minimum temperature of 100°F. An acceptable alternative cure would be to slowly heat the adhesive to 125°F and cure for 2 hours.
   NOTE: If the test engineer has determined that the test article cannot be warmed to the stated cure temperature, then, the gage installation must be cured overnight at a minimum temperature of 80°F.
9. Following the basecoat cure, abrade the basecoat until a uniform surface is achieved. This sanding operation should remove only an amount of the GA-2 sufficient to expose the fiber surface peaks.

10. Clean the basecoat areas once more with the alcohol.

Installation of the Gages

NOTE: The following strain gage installation procedure is applicable for long-term or repeat-testing of the particular test article. If it can be absolutely determined that the test article being gaged will be tested within 6 weeks of the gaging operation and that no testing after 6 weeks is to be performed, then, M-Bond 200 adhesive can be substituted for GA-2 for the gage installation steps. For typical Gr/Ep porous surfaces, the GA-2 basecoat would still be necessary. The gaging procedure to be followed for M-Bond 200 is offered by Micro-Measurements, Inc. as per their Tech Tip "Instruction Bulletin B-127-9. This instructional bulletin is included as an addendum at the end of this memorandum. The following steps are applicable for gaging this material with M-Bond GA-2.

1. Areas to be gaged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in appropriate locations on the GA-2 basecoat to coincide with the alignment marks around the four sides of the gage on the backing.
3. Each gage to be installed should be placed on a clean glass plate, underside down. A piece of teflon tape (CHR, Inc. type C) is then applied to the top side of the gage.
4. The gage is then transferred to the test article and positioned in the area where the gage alignment marks have been made.
5. Then lift the gage up at one end using the teflon tape. Fold the gage back such that the underside of the gage is up.
6. Brush a layer of GA-2 adhesive onto the underside of the gage and the GA-2 basecoat.
7. When the viscosity of the GA-2 is appropriate (if too thin or too viscous a glue-line with uniform thickness is difficult to obtain), lift the gage again from the end and place it back in position on the basecoat.
8. Apply a vacuum pad over the gage installation, generate the vacuum, and maintain the vacuum for a minimum of 4 hours with the test article at 100° F, or 2 hours at 125° F when permitted.
   NOTE: If the test engineer has determined that the test article cannot be warmed to the stated cure temperature, then, the gage installation must be cured overnight at a minimum temperature of 80° F.
9. Finally, remove the vacuum pad and the teflon tape. Inspect the installation for voids, uneven glue-line, and gage alignment.

Wiring the Gage

1. With a hard rubber eraser, remove any oxidation from the gage soldering pad.
2. Check the gage resistance to verify that it is within the manufacturer's specifications.
3. Tin the soldering pads.
4. Strip both ends of the lead wires and check for nicks in the strands.
5. Tin the lead wires.
6. Position the lead wires at the end of the gage and provide a mechanical strain relief in the lead wires near the gage.
7. Secure the lead wires to the surface of the test article and solder the wires to the gage solder pads.
8. Remove flux residue from the solder joints.
9. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
10. Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure
Typically, the only moisture-proofing applied to this type of installation is M-Coat A. This coating is applied only to the solder joints and exposed wires in order to provide a measure of oxidation prevention for long-term testing in a laboratory environment. When a given test article is to be subjected to a more harsh environment, that environment will dictate the protective coating system to be utilized. There are numerous test scenarios requiring more elaborate coating schemes. They are too numerous to warrent listing here.

INSTALLATION TYPE 2 - The following materials and procedures are applicable for gaging Graphite/Epoxy (Gr/Ep) Composites for Elevated Temperature (250° F) to Cryogenic Temperature (to -452° F) Testing

NOTE: The following materials and procedures are applicable for graphite-based composite test articles that are to be tested at temperatures ranging from 250° F down to -452° F. These materials and procedures assume that the surface(s) to be gaged are not so coarse as to require a "basecoat adhesive" prior to installation of the gages. If it is determined that the surfaces are this coarse, a basecoat of Hysol EA934NA structural adhesive should be applied, cured at 275° F for 4 hours, and then sanded in a manner to provide an appropriate texture for the following gaging procedure. Also, to date, testing in a liquid helium environment using the Hysol adhesive as a strain gage basecoat, has not been verified. Therefore, while this technique has been proven at liquid nitrogen temperatures, the test engineer should be made aware that this is an unproven gaging method. As always, there may be exceptions to the stated installation procedures. The testing parameters will dictate the gages, adhesives, moisture-barriers, etc., best suited to a particular task. **All of the test conditions must be reviewed with the test engineer** prior to commencing strain gage related efforts.

Gaging Materials (all materials that are an integral part of the strain gaged test article
1. Gage type: to be designated by test engineer, typically CEA series for 250° F testing and SK or WK series (Micro-Measurements) for cryogenic testing
2. Adhesive type: M-BOND 610 (Micro-Measurements) see note above for possible use of basecoat
3. Wiring Terminals type (when needed): CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of gages will determine which size is appropriate
4. Gage-to-Terminal Jumper Wire (when required): AWG#38 silver-clad copper
5. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor flat ribbon, AWG#30. For Cryogenic testing, leadwires must be teflon insulated.
6. Solder type: 361-A (Micro-Measurements)
7. Protective Gage-coating type: wide variation depending on testing parameters-must be determined for each task

Surface Preparation for Gaging
1. Clean the areas to be gaged by flushing them with ENSOLV. Be careful not to wash surface contaminants back into the initially flushed areas by flushing through those areas from adjacent areas with a second washing.
2. Perform microscopic examination of test article looking for surface flaws and other anomalies.
3. Again, flush areas to be gaged with ENSOLV. Be careful not to bring surface contaminants back

into the initially washed areas.

4. Mask appropriate areas to be gaged and micro-sandblast using 50 micron Al2O3 abrasive powder or 280 grit silicon/carbide abrasive paper as appropriate.
5. Remove masking tape.
6. Flush areas to be gaged using ENSOLV as in Step 3.
7. Finally, flush areas as in Step 3 and Step 6 using alcohol. Application of the strain gage adhesive (or basecoat) should begin immediately following this step.

Installation of the Gages

1. Gages (and terminals when used) should be cleaned with pure alcohol, dried, and placed on a clean glass plate, inverted and ready for installation.
2. Apply a coat of M-BOND 610 to the underside of the gages and terminals to be installed as well as a coat to the appropriate test article surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature.
4. Place the gages and terminals on the test article surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages are located.
6. Apply a constant and uniform pressure of 40 psi to the rubber pads using an appropriate clamping device.
7. Place the test article in a temperature chamber and raise the temperature to 250° F.
8. Hold the gaged test article at 250° F for a minimum of three hours.
9. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installation for accuracy of alignment, glue-line voids, or foreign matter.
10. Post cure the installation at 275° F for two hours.

Wiring the Composite Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these gages should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage to two places at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All intrabridge (when required) and interbridge (when required) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
7. When possible, all intrabridge wires (when required) should be of equal resistance and length.
8. Wire routing should be preplanned with no wiring to be routed over the strain gage active grids or the gage jumpers.
9. When all wiring is completed, the test article should be cleaned to remove all soldering residues and other foreign matter.
10. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
11. If wired as bridges, check to confirm that the zeros are representative of the arbitrary differences in

the resistances of the four gages that comprise the bridge circuit.

12.Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure

Depending on the testing parameters, moisture protection may or may not be needed. Many factors must be reviewed in order to provide the appropriate coating over strain gage installations. Factors such as range of temperature the gages will encounter during testing, amount of moisture to be encountered, reinforcing effect on thin surfaces to be strained, short-term or long-term testing, and others must be weighed. Because gage coatings are custom-matched to the task, no particular moisture-proofing procedure is detailed here.

INSTALLATION TYPE 3 - The following materials and procedures are applicable for gaging SILICON-CARBIDE COATED CARBON BASED COMPOSITES for structural analysis or materials properties testing at ROOM TEMPERATURE.

Gaging Materials (all materials that are an integral part of the strain gaged composite)

1. Gage type: to be designated by test engineer, typically CEA series (Micro-Measurements)
2. Adhesive type: M-Bond GA-2 (Micro-Measurements). See notes* below
3. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor flat ribbon, size AWG#30, stranded, silver-plated copper with a vinyl insulation over each conductor
4. Solder type: 361-A (Micro-Measurements)
5. Protective Gage Coating type: M-Coat A (Micro-Measurements)

Surface Preparation for Gaging

1. Perform general degreasing and cleaning of the surface(s) to be gaged using ENSOLV and 200 proof alcohol.
2. Visually examine (microscopic when possible) the areas to be gaged checking for cracks, broken fibers, voids, etc. Micro-cracks (crow's feet) may be observed over the entire surface when the carbon composite is coated with silicon-carbide. This would not necessarily indicate that the article is flawed.
3. Mask the areas to be gaged using 3-M tape type: 46. Next, sandblast using #30 grit silicon-carbide abrasive powder. Do not allow the abrasive to dwell on an area more than a few seconds. This abbreviated sandblasting time will prevent the sandblast abrasive from removing too much surface material.
4. Remove the masking tape, then, using dry shop air, remove abrasive powder residue.
5. Clean the surface again with 200 proof alcohol.
   NOTE: Because the silicon-carbide carbon composites typically contain micro-cracks and because the coarse sandblasting leaves the surfaces quite rough for gaging, a basecoat should be applied in the areas to be gaged. The following procedure works well.
6. Apply a liberal coat of GA-2 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
7. On flat surfaces this basecoat can be left to dry as is. On surfaces where sag or runoff is a concern, place a teflon film pad over the basecoat, install a vacuum applicator pad over the teflon,

and apply vacuum to the applicator pad.

8. Cure the test article for 4 hours at a minimum temperature of 100°F. An acceptable alternative cure would be to slowly heat the adhesive to 125°F and cure for 2 hours.
9. Following the basecoat cure, abrade the basecoat until a uniform surface is achieved.
10. Clean the basecoat areas once more with the alcohol.

Installation of the Gages

NOTE: The following strain gage installation procedure is applicable for long-term or repeat-testing of the particular test article. If it can be absolutely determined that the test article being gaged will be tested within 6 weeks of the gaging operation and that no testing after 6 weeks is to be performed, then, M-Bond 200 adhesive can be substituted for GA-2 for the gage installation steps. The basecoat of GA-2 would still be required. The gaging procedure to be followed for M-Bond 200 is offered by Measurements Group, Inc. as per their Tech Tip "Instruction Bulletin B-127-9. This instructional bulletin is included as Addendum #3. The following steps are applicable for gaging this material with M-Bond GA-2.

1. Areas to be gaged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in appropriate locations on the GA-2 basecoat to coincide with the alignment marks around the four sides of the gage on the backing.
3. Each gage to be installed should be placed on a clean glass plate, underside down. A piece of teflon tape (CHR, Inc. type C) is then applied to the top side of the gage.
4. The gage is then transferred to the test article and positioned in the area where the gage alignment marks have been made.
5. Then lift the gage up at one end using the teflon tape. Fold the gage back such that the underside of the gage is up.
6. Brush a layer of GA-2 adhesive onto the underside of the gage and the GA-2 basecoat.
7. When the viscosity of the GA-2 is appropriate (if too thin or too viscous a glue-line with uniform thickness is difficult to obtain), lift the gage again from the end and place it back in position on the basecoat.
8. Apply a vacuum pad over the gage installation, generate the vacuum, and maintain the vacuum for a minimum of four hours with the test article at 100°F. A two-hour cure at 125°F is also acceptable.
9. Finally, remove the vacuum pad and the teflon tape. Inspect the installation for voids, uneven glue-line, and gage alignment.
10. Flush the installation with pure alcohol.

Wiring the Gage

1. With a hard rubber eraser, remove any oxidation from the gage soldering pad.
2. Check the gage resistance to verify that it is within the manufacturer's specifications.
3. Tin the soldering pads.
4. Strip both ends of the lead wires and check for nicks in the strands.
5. Tin the lead wires.
6. Position the lead wires at the end of the gage and provide a mechanical strain relief in the lead wires near the gage.
7. Secure the lead wires to the surface of the test article and solder the wires to the gage solder pads.
8. Remove flux residue from the solder joints.
9. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
10. Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure
Typically, the only moisture-proofing applied to this type of installation is M-Coat A. This coating is applied only to the solder joints and exposed wires in order to provide a measure of oxidation prevention for long-term testing in a laboratory environment. When a given test article is to be subjected to a more harsh environment, that environment will dictate the protective coating that will be utilized. The various test scenarios requiring more elaborate coating schemes are too numerous to list here.

INSTALLATION TYPE 4 - The following materials and procedures are applicable for gaging METAL MATRIX BASED COMPOSITES for structural analysis or materials properties testing at ROOM TEMPERATURE.

NOTE: To date, all metal matrix composites that have required strain gages for testing at Langley have had titanium or aluminum as the matrix material. No special gage installation procedure is required for these materials at room temperature other than the recognition that they oxidize rapidly, therefore, the application of the gage should begin immediately following the surface preparation steps. Micro-Measurements, Inc. Instruction Bulletin B-127-9 titled "Strain Gage Installations with M-Bond 200 Adhesive" is to be utilized for installing gages on these materials when short-term testing is required. This bulletin is included in Addendum #3. For long-term testing, the gaging procedure used in "**INSTALLATION TYPE 1**" for this **APPLICATION CLASS III** can be used.

INSTALLATION TYPE 5 - The following materials and procedures are applicable for gaging METAL MATRIX BASED COMPOSITES for structural analysis or materials properties testing in the temperature range of -320°F to 400°F.

Gaging Materials (all materials that are an integral part of the strain gaged composite)
1. Gage type: to be designated by test engineer, typically SK or WK series (Micro-Measurements)
2. Adhesive type: M-Bond 610 (Micro-Measurements)
3. Wiring Terminals type: CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of gages will determine which size is appropriate
4. Gage-to-Terminal Jumper Wire (when required): AWG#38 silver-clad copper
5. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor, twisted, size AWG#30, stranded, silver-plated copper with teflon insulation over each conductor. An alternate is a Teflon, 3-conductor ribbon, AWG #30(7-38).
6. Solder type: 361-A (Micro-Measurements) for -320°F to 300°F tests and 430-20S (Micro-Measurements) for testing to 400°F.
7. Protective Gage Coating type: RTV-159 (General Electric) for testing to 400°F
   NOTE: When possible, gaseous nitrogen purging should be used to prevent condensation from forming, thus, eliminating the need for a moisture-barrier. If cryogenic testing only is required, a very thin coat of M-Coat B may be substituted for the RTV-159.

Surface Preparation for Gaging

1. Clean the areas to be gaged. This is accomplished by scrubbing with an Ammonia based neutralizer (M-M type: M-PREP Neutralizer 5A works well).
2. Perform microscopic examination of the test article looking for flaws in surface, nicks, exposed fibers, warped surfaces.
3. Rinse the composite with pure alcohol.
4. Mask appropriate areas of the test article for micro-sandblasting operation.
5. Micro-sandblast areas to be gaged using 50 micron $Al2O3$ abrasive powder.
6. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
7. Repeat the alcohol rinse operation. Installation of the gages must begin immediately following this step.
8. When more than one gaging adhesive cure cycle is required, the previous 6 steps must be repeated for each curing cycle.

Installation of the Gages

1. Gages and terminals should be cleaned with pure alcohol, dried, and placed on a clean glass plate, inverted and ready for installation.
2. Apply a coat of M-610 to the underside of the gages and terminals to be installed as well as a coat to the appropriate test article surfaces.
3. Allow the items coated with M-610 to air dry at least ten minutes at room temperature.
4. Place the gages and terminals on the composite surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
5. Next, place silicone rubber pads over the tape in the areas where the gages and terminals are located.
6. Apply a constant and uniform pressure of 60 psi to the rubber pads using an appropriate clamping device.
7. Place the test article in a temperature chamber and slowly raise the temperature of the article to 340°F. This heating rate should be approximately 6°F/minute.
8. Hold the article at this temperature for one hour, then, cool it.
9. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installations for accuracy of alignment, glue-line voids, or foreign matter.
10. When more than one cure cycle is required to complete all gage installations on the test article, the gage areas still requiring gages should be micro-sandblasted again with a repeat of the surface preparation steps previously outlined.
11. To post cure the gage installations, slowly raise the temperature of the test article at the same rate utilized for installing the gages until a temperature of 350°F is reached for the 300°F testing, and 450°F is reached for the 400°F testing.
12. Hold the test article at the appropriate temperature for two hours. Cool the composite and repeat the inspection of the gages.

Wiring the Composite Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these gages should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a

guide.
4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage to two decimal places at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All intrabridge (when required) and interbridge (when required) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
7. When possible, all intrabridge wires (when required) should be of equal resistance and length.
8. Wire routing should be preplanned with no wiring to be routed over the strain gage active grids or the gage jumpers.
9. When all wiring is completed, the test article should be cleaned to remove all soldering residues and other foreign matter.
10. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
11. If wired as bridges, check to confirm that the zeros are representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit.
12. Check the resistance leakage to ground. This should be >10K Megohms.

<u>Moisture-Proofing Procedure</u> (when purging is not feasible)
1. For the composites that are to be tested in the temperature range of -320°F up to 150°F, M-Coat B is to be utilized.
2. First, clean the test article with 200 proof alcohol.
3. Next, apply a very thin coat (approximately .003" thick) of the M-Coat B over all exposed solder joints and uninsulated wiring. Do not allow the coating to cover any portion of the active grids of the strain gages.
4. Allow this coat to air dry at least 2 hours in the laboratory environment.
5. Apply a second coat of M-COAT B over the first coat such that it encapsulates the first coat. Apply it as before.
6. For the composites that are to be tested up to 400°F, first, clean the test article with 200 proof alcohol.
7. Next, apply a coat of RTV-159 (approx. .030" thick) to the areas described in Step 3. This should be done with the test article and the RTV at a minimum temperature of 72°F and the relative humidity not more than 40 percent. Allow to air dry overnight before testing.

INSTALLATION TYPE 6 - The following materials and procedures are applicable for gaging METAL MATRIX BASED COMPOSITES for structural analysis or materials properties testing up to 700°F.

NOTE: For testing at temperatures above 400°F but not exceeding 700°F, consideration must be given to the test parameters. Determination of the gaging materials and application procedure will depend on factors including the actual test temperature, the duration of the test(s), strain levels, data accuracy requirements, static or dynamic testing, etc. Therefore, the gaging procedure must be custom suited to the test scenario. Because of this, no particular gage application procedure is detailed here. However, one particular gaging scenario for a Ti-6 panel to be tested at temperatures ranging from - 300°F to 650°F is described in **<u>APPLICATION CLASS V</u>, INSTALLATION TYPE 3**. The "Surface Preparation for Gaging" steps described in **INSTALLATION TYPE 5** in this section, should be

applicable for all metal matrix based composites.

INSTALLATION TYPE 7 - The following materials and procedures are applicable for gaging ADHESIVE/POLYMER BASED COMPOSITES for structural analysis or materials properties testing at ROOM TEMPERATURE

Gaging Materials (all materials that are an integral part of the strain gaged composite)
1. Gage type: to be designated by test engineer, typically CEA series (Micro-Measurements)
2. Adhesive type: M-Bond GA-2 (Micro-Measurements). See notes* below
3. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor flat ribbon, size AWG#30, stranded, silver-plated copper with a vinyl insulation over each conductor
4. Solder type: 361-A (Micro-Measurements)
5. Protective Gage Coating type: M-Coat A (Micro-Measurements)

Surface Preparation for Gaging
1. Perform general degreasing and cleaning of the surface(s) to be gaged using 200 proof alcohol.
2. Visually examine (microscopic when possible) the areas to be gaged checking for cracks, broken fibers, voids, etc.
3. Mask the areas to be gaged and micro-sandblast using 50 micron aluminum-oxide abrasive powder. Do not allow the abrasive to dwell on an area more than a few seconds. This will prevent the sandblast abrasive from removing too much surface material.
4. Remove masking tape, then, using dry shop air, remove abrasive powder residue.
5. Clean the surface again with 200 proof alcohol.
   *NOTE: There are instances when the surfaces of these composites are too rough for installing strain gages. When this is encountered, a basecoat should be applied in the areas to be gaged. The following "basecoating" procedure works well.
6. Apply a liberal coat of GA-2 adhesive to the sandblasted areas with a thickness sufficient enough to cover the peaks of the rough surface.
7. On flat surfaces this basecoat can be left to dry as is. On surfaces where sag or runoff is a concern, place a thin teflon sheet over the basecoat, install a vacuum applicator pad over the teflon, and apply vacuum to the applicator pad.
8. Allow the GA-2 basecoat to cure for at least 6 hours at 100°F. An alternative cure, usually acceptable to the project engineer, would be to slowly heat the adhesive to 125°F and cure for 4 hours.
   *NOTE: If the test article cannot be subjected to temperatures above room temperature, then, the GA-2 must be cured overnight at a minimum temperature of 72°F with the relative humidity not more than 40 percent.
9. Following the basecoat cure, abrade the basecoat until a uniform surface is achieved. This sanding operation should remove only an amount of the GA-2 sufficient to expose the surface peaks.
10. Clean the basecoat areas once more with the alcohol.

Installation of the Gages
*NOTE: The following strain gage installation procedure is applicable for long-term or repeat-testing of the particular test article. If it can be absolutely determined that the test article being gaged will be

tested within 6 weeks of the gaging operation and that no testing after 6 weeks is to be performed, then, M-Bond 200 adhesive can be substituted for GA-2 for the gage installation steps. The GA-2 basecoat may still be necessary. When the M-Bond 200 is to be utilized, the gaging procedure to be followed is the procedure offered by Measurements Group, Inc. as per their Tech Tip "Instruction Bulletin B-127-9. This instructional bulletin is included as Addendum #3. The GA-2 gaging procedure is as follows:

1. Areas to be gaged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in appropriate locations on the GA-2 basecoat (or composite surface) to coincide with the alignment marks around the four sides of the gage on the backing.
3. Each gage to be installed should be placed on a clean glass plate, underside down. A piece of teflon tape (CHR, Inc. type C) is then applied to the top side of the gage.
4. The gage is then transferred to the test article and positioned in the area where the gage alignment marks have been made.
5. Then lift the gage up at one end using the teflon tape. Fold the gage back such that the underside of the gage is up.
6. Brush a layer of GA-2 adhesive onto the underside of the gage and the GA-2 basecoat.
7. When the viscosity of the GA-2 is appropriate (if too thin or too viscous a glue-line with uniform thickness is difficult to obtain), lift the gage again at one end and place it back in position on the basecoat.
8. Apply a vacuum pad over the gage installation, generate the vacuum, and maintain the vacuum for a minimum of 6 hours at 100°F, or 4 hours at 125°F, or overnight if at room temperature.
9. Finally, remove the vacuum pad and the teflon tape. Inspect the installation for voids, uneven glue-line, and gage alignment.

Wiring the Gage

1. With a hard rubber eraser, remove any oxidation from the gage soldering pad.
2. Check the gage resistance to verify that it is within the manufacturer's specifications.
3. Tin the soldering pads.
4. Strip both ends of the lead wires and check for nicks in the strands.
5. Tin the lead wires.
6. Position the lead wires at the end of the gage and provide a mechanical strain relief in the lead wires near the gage.
7. Secure the lead wires to the surface of the test article and solder the wires to the gage solder pads.
8. Remove flux residue from the solder joints.
9. Check the resistance at the end of the leadwires to verify that the total resistance is appropriate for this particular gage and lead wire system.
10. Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure

Typically, the only moisture-proofing applied to this type of installation is M-Coat A. This coating is applied only to the solder joints and exposed wires in order to provide a measure of oxidation prevention for long-term testing in a laboratory environment. When a given test article is to be subjected to a more harsh environment, that environment will dictate the protective coating that is to be utilized. The various test scenarios requiring more elaborate coating schemes are too numerous to list here.

SUMMARY STATEMENT FOR STRAIN GAGING COMPOSITES WITH CONVENTIONAL GAGING MATERIALS

The materials and installation techniques detailed for gaging composites are applicable for most applications. However, several factors may necessitate a deviation in the stated gaging details in this section. Such factors as, very high strain levels, number of load cycles, duration of the test, testing timetable, testing environment, composites susceptible to chemical damage, and costs can dictate changes in the stated gaging procedures. Prior to beginning any gaging task, a review with the project engineer should be conducted where all of the test parameters are discussed. This will help assure that the appropriate materials and techniques are utilized in the gage installation process.

<u>APPLICATION CLASS IV</u> - GAGE INSTALLATION PROCEDURES FOR HIGH-TEMPERATURE TEST ARTICLES - TESTING ABOVE 700°F

NOTE: The materials and techniques employed for installing high-temperature gages vary for almost every article to be gaged. The procedures detailed here have been written either for a particular test article or a particular gage or both. The procedures described for the four installation types in this class of application have been successfully employed on test articles up to 1500°F. Modifications to the installation procedures may be required in order to expand the maximum achievable test temperature for each installation type described here to temperatures beyond 1500°F. The procedures detailed in this section are to be used as a guide only. As with conventional gages, a thermal cycling of the installed gages at or above the maximum test temperature will enhance the accuracy of the first cycle test data. It is recommended that this be suggested to the test engineer prior to delivering the installed gages. For the "INSTALLATION TYPE 1" installation procedure note that the gage is actually a half-bridge with one active element (bonded) and one compensating element (tack-bonded only, on the basecoat).

INSTALLATION TYPE 1 - The following materials and procedures are applicable for INCONELS and TITANIUM MATRIX COMPOSITES using Gage Type:LARC-CKA1-1B

<u>Gaging Materials (all materials that are an integral part of the test article)</u>

1. Gage type: LARC-CKA1-1B [gage type for TMC is LARC-CKA1-1B .66] (JP Technologies)
2. Aluminum Oxide (Al_2O_3) rod and powder (Hitec Products)
3. Nextel 312 woven cloth, .010" thick, for thermal blanket (3M Company)
4. Lead Wires, type: Hoskins Alloy #875, AWG #25, 3-conductor with Nextel 312 sleeving over each conductor plus a Nextel 312 overbraiding over all three conductors (Santa Fe Textiles)
5. Annealed Inconel strapping for lead wire hold-down (J P Technologies)

NOTE: Following is a detailed step-by-step procedure which has been developed and utilized for installing the subject "<u>compensated type</u>" strain gages on Inconel 100 and Beta 21S TMC surfaces. These procedures are written with the assumption that the user has access to plasma thermal spray hardware. The plasma spray step is considered optional and may be eliminated for most applications with these particular gages. However, it was observed, with limited lab testing, that maximum test temperature and strain range for the gages were obtained when the plasma spray system was utilized in conjunction with the oxygen/acetylene (Rokide) spray gun.

STEP 1: Locate the area where the strain gages are to be installed and clean the area with an appropriate degreaser. Measurements Group, Inc. spray cleaner, type: FTF-1, works well.

STEP 2: Mask around the area to be gaged using a tape that can withstand coarse grit sandblasting. The masking should provide an open area .6" wide by .7" long which is to be sandblasted. A high temperature fiberglass tape such as 3-M type: 64 works well.

STEP 3: Now micro-sandblast the open area within the masking using 50 micron Aluminum Oxide (Al_2O_3) abrasive powder. This step removes any surface coatings or surface oxidation which may be present. This step also provides a uniformly textured surface which is visually beneficial during

the coarse sandblasting step.

STEP 4: Next, coarse sandblast the micro-sandblasted area with a #30 grit silicon carbide abrasive powder in order to generate a coarse texture for the thermal spraying operations that are to come later. Care must be exercised in this operation to keep the sandblasting at a minimum. Excessive passes with the sandblast gun could damage the surface of the area being textured.

STEP 5: After this, remove the masking tape and clean the area again with the FTF-1 spray cleaner. Follow this by swabbing the area with 200 proof grain alcohol.

STEP 6: Mask around the sandblasted area, again, using the high temperature tape.

STEP 7: Set-up a system of compressed air adjacent to the area to be flame sprayed in order to provide a measure of cooling in this area during flame spray operations. Air pressure should be maintained at a low level to prevent disturbing the flow of molten aluminum oxide from the plasma or oxygen/acetylene flame spray gun.
NOTE: This compressed air is to be utilized for each flame spray operation throughout the remaining high temperature gaging steps listed here.

STEP 8: (Optional) Plasma spray a basecoat of Al_2O_3 to the sandblasted surface within the masked area. This first layer of gaging basecoat should be approximately .001" thick. This initial flame spray operation should take place within 30 minutes of the last sandblast operation.

STEP 9: To complete the basecoat, a second coat of Al_2O_3 is to be applied to the initial basecoat (STEP 8) using a Rokide flame spray gun. This layer of Al_2O_3 plus the original layer should total approximately .003" in thickness.
NOTE: The initial basecoating step (STEP 8) utilizing the plasma sprayed Al_2O_3 is optional, but fewer gage failures on TMC have been observed at 1500°F when this technique has been employed.

STEP 10: Next, position and secure the pair of gages (active and compensating), with their top carrier and sub carrier, to the basecoat.

STEP 11: At this point, the gage resistances should be checked and recorded.

STEP 12: Initial bonding of the exposed active gage convolutes, the exposed gage ribbons, and the exposed "tack-bond" areas of the compensating gage, should now be undertaken using a Rokide gun. Aluminum oxide rods (Norton type: SA) are to be utilized. Keep the amount of to a minimum.

STEP 13: The next step is to carefully remove the top carrier and sub carrier tape segments from the active gage. With this done, inspect and remove any ridges of Al_2O_3 that may have formed adjacent to the carrier tape strips. An aluminum oxide abrasive stone or a pointed diamond file can be employed for this task. This task is to be performed under a microscope.

STEP 14: Final bonding of the active gage is next. The Rokide gun is again employed for this operation. Aluminum oxide rods of the same type that were utilized for the initial bonding of the gage convolutes is to be employed here. Flame spray all exposed areas making certain to cover the entire gage. Keep the total thickness to a minimum. Remember to use the compressed air to prevent the strain gage surface from overheating. A typical completed installation should be approximately .015" thick.

STEP 15: Remove the remaining top carrier being careful to insure that the sub carrier remains in place.

NOTE: Steps 16 through 20 are optional. These steps detail the requirements for adding a "window frame border" of aluminum oxide Al_2O_3 around the entire installation for the purpose of minimizing the difference in temperature between the active gage and the compensating gage when air flows or fast heat-up rates are expected. This window frame border is actually a ridge of which forms a boundary for the thermal blanket.

STEP 16: Remove .100" of the sub carrier tape from the leadwire end of the gages. Also, remove .030" (this dimension may be revised depending on the overall width of the carrier tape furnished with the gages) from the remaining three sides (outside perimeter) of the sub carrier tape. This is done in order to expose the basecoat of Al_2O_3 and allows for the forming of the window frame border.

STEP 17: Next, add two layers of high temperature tape around the perimeter of the sub carrier tape leaving a .030" gap on all four sides.

STEP 18: Add two layers of high temperature tape over the sub carrier tape, cut to the same size as the sub carrier tape.

STEP 19: Using Rokide, flame spray the .030" perimeter gap until the Al_2O_3 fills the gap to the top of the tape. This completes the formation of the window frame border (ridge of Al_2O_3).

STEP 20: Remove all of the added tape being careful not to disturb the sub carrier tape.

STEP 21: Now, carefully remove the individual segments of the sub carrier tape. Compensating gage convolutes must be kept flat against the basecoat. The installed gage elements are now ready for the thermal blanket which is furnished with the gage.

STEP 22: Perform a final microscopic inspection of the installation. If no imperfections in the coating are observed, make another electrical check of the gage resistance and the gage resistance to ground.

STEP 23: Install the thermal blanket over both gage elements. The blanket should fit within the confines of the framing border (when framing border is utilized). The thermal blanket consists of a sheet of Nextel 312 cloth, .010" thick, which has had its top surface flame sprayed with a .005" thick layer of Al_2O_3. This sheet of Nextel is then cut to size to fit within the confines of the perimeter framing border.

STEP 24: Secure the thermal blanket with spotwelded straps or ceramic cement.

Step 25: Make final electrical checks and install leads.

NOTE: Lead wire connection involves many tasks in preparing the exit lead wiring and the strain gage leads (or ribbons) for the spotwelding operations that are typically used in high-temperature strain gage electrical connections. Variables in the spotwelder probes and the spotwelder operational functions also play a role in determining just how the junction between the gage lead and the exit lead will be facilitated. Therefore, detailed procedures for high-temperature lead wire connection are not offered here.

A MORE DETAILED WRITE-UP (WITH PHOTOCOPIES) FOR THIS TYPE OF INSTALLATION PROCEDURE IS INCLUDED IN ADDENDUM #4 AT THE END OF THE TEXT

INSTALLATION TYPE 2 - The following materials and procedures are applicable for BETA 21S TMC using high-temperature foil gage, type: NZ-2104-120L

Gaging Materials (all materials that are an integral part of the test article)

1. Gage type: NZ-2104-120L (JP Technologies)
2. Aluminum Oxide (Al_2O_3) rod and powder (Hitec Products)
3. Lead Wires, type: Hoskins Alloy #875, AWG #25, 3-conductor with Nextel 312 sleeving over each conductor plus a Nextel 312 overbraiding over all three conductors (Santa Fe Textiles)
4. Annealed Inconel strapping for lead wire hold-down (J P Technologies)

NOTE: Following is a detailed step-by-step procedure which has been developed at Langley for installing free-filament, foil-type high-temperature strain gages (type:NZ-2104-120L) on Beta 21S Titanium Matrix Composites (TMC). These procedures are written for strain gaging this material only, but most of the steps should be applicable to other TMC test materials and other free-filament gage types.

Gage Installation Procedure

A visual inspection of the test article is to be made prior to initiating the strain gaging effort. Record all flaws in the "comment" section of the "LARC STRAIN GAGING INFORMATION" form (FORM FL-1). Assuming the article to be acceptable for gaging, proceed with the high-temperature strain gage installations utilizing the steps below. Also, FORM FL-1 (or an equivalent) is to be used to record all pertinent gaging information.

STEP 1: Locate the area where the strain gage is to be installed and clean with an appropriate degreaser. Measurements Group, Inc. spray cleaner, type: FTF-1, works well.

STEP 2: Mask the area to be gaged using a tape that can withstand coarse grit sandblasting. A high temperature fiberglass tape from Connecticut Hard Rubber Company (CHR) works well.

STEP 3: Now micro-sandblast the masked area using 50 micron Aluminum Oxide Al_2O_3 abrasive powder. This step removes any surface coatings or surface oxidation which may be present. This step also provides a uniform surface color which is beneficial during the coarse sandblasting step.

STEP 4: Next, coarse sandblast the micro-sandblasted area with a #30 grit silicon carbide abrasive powder in order to generate a coarse texture for the thermal spraying operations that are to come later. Care must be exercised in this operation to keep the sandblasting at a minimum. Excessive passes with the sandblast gun could damage the surface of the area being textured.

STEP 5: After this, remove the masking tape and clean the area again with the FTF-1 spray cleaner. Follow this by swabbing the area with 200 proof alcohol.

STEP 6: Mask the area again using the high temperature tape.

STEP 7: Set-up a system of compressed air adjacent to the area to be flame sprayed in order to provide a measure of cooling for this area during flame spray operations. Air pressure should be maintained at a low level to prevent disturbing the flow of molten aluminum oxide from the flame spray gun. NOTE: Whenever possible, this compressed air is to be utilized for each flame spray operation throughout the remaining high temperature gaging steps listed here.

STEP 8: Plasma spray a basecoat of Al_2O_3 to the surface within the masked area. This first layer of gaging basecoat should be approximately .001" thick. This initial flame spray operation should take place within 30 minutes of the last sandblast operation.

STEP 9: To finish the basecoat, a second coat of Al_2O_3 is to be applied to the initial basecoat (STEP 8) using a Rokide flame spray gun. This layer of Al_2O_3 plus the original layer should total approximately .003" in thickness.

STEP 10: Next, position and secure the NZ gage, with its carrier, to the Al_2O_3 basecoat. Additional carrier tape strips are to be added across the gage convolutes to prevent the gage convolutes from buckling during the initial gage bonding, flame spray operation. The added strips, roughly .030" wide, are placed outside of the original carrier strips with .050" spacing being maintained.

STEP 11: At this point, the gage resistance is checked and recorded as per the strain gaging information form, FORM FL-1.

STEP 12: Initial bonding of the gage convolutes should now be undertaken using a Rokide gun. Aluminum oxide rods (Norton type:SA) are to be used to cover the exposed areas of the gage. Keep the amount of Al_2O_3 to a minimum.

STEP 13: The next step is to remove the carrier tape. With this done, inspect and remove any ridges of Al_2O_3 that may have formed adjacent to the carrier tape strips. An aluminum oxide abrasive stone or a pointed diamond file can be employed for this task.

STEP 14: Final bonding of the gage is next. The Rokide gun is again used for this operation. Aluminum oxide rods of the same type that were utilized for the initial bonding of the gage convolutes are to be employed here. Flame spray all exposed areas making certain to cover the entire gage. Keep the total thickness to a minimum. Remember to use the compressed air to prevent the TMC surface from overheating. A typical completed installation should be approximately .015" thick.

STEP 15: Perform a final microscopic examination of the installation. If no imperfections in the coating are observed, make final electrical checks and record the gage resistance and the gage leakage resistance to ground.

STEP 16: The previous steps are to be followed in the order listed for each NZ type gage that is to be installed. Upon completion of all of the above steps and prior to lead wire installation, check the gage resistance again. If the resistance of the gage has deviated more than .5 ohms since the STEP 15 resistance check, it should be replaced.

NOTE: For the reasons stated in the note at the end of "Installation Type 1", no lead wire connection procedures are offered here.

INSTALLATION TYPE 3 - The following materials and procedures are applicable for Silicon/Carbide Coated Carbon/Carbon Composites with Most Free-filament Gages

Gaging Materials (all materials that are an integral part of the test article)

1. Gage types: only restrictions are that gages should be at least 1/4" active grid length and that gages should be 2 mil diameter, minimum (this of course precludes the use of foil-type high-temperature gages)
   NOTE: Localized stress risers at seams in the SiC coating appear to be the reason for a higher loss rate in gages with small cross sectional areas. Also, a reduction in the scatter of the indicated modulus for this type of composite has been observed when gage lengths of 1/4" or longer have been utilized.
2. Aluminum Oxide (Al_2O_3) rod and powder (Hitec Products)
3. Lead wire hold-down adhesives, type: LEX-10 (Hitec Products) and type: Omega CC (Omega Engineering)
4. Lead Wires, type: Hoskins Alloy #875, AWG #25, 3-conductor with Nextel 312 sleeving over each conductor plus a Nextel 312 overbraiding over all three conductors (Santa Fe Textiles)

Gage Installation Procedure

NOTE: The gaging procedures described in the two previous "installation types" can be used as a guide for installing high-temperature gages on this type of composite material. There are two areas involved in the installation that must be approached differently, however. One area is the surface preparation; the other is the attachment of the lead wires. Each is described here.

Surface Preparation and Basecoat Installation

1. Spray clean all areas where gages are to be placed using a mild degreaser such as Micro-Measurements, FTF-1 solvent. Also, spray clean all areas where lead wires will be secured to the test article surface.
2. Mask the areas where gages are to be located and the spots where lead wires are to be adhesively bonded to the surface (see details below).
3. Sandblast the masked areas where gages are to be installed using #30 grit silicon/carbide abrasive powder. Do not allow the sandblast abrasive to dwell on an area more than a few seconds in order to avoid removing too much of the SiC coating.
4. The basecoat for the gages can now be applied as described in the previous two installation procedures.
5. The lead wires require a basecoat, also. This is to be a ceramic cement. The installation of that basecoat and the lead wires is described below.

Lead Wire Hold-down to Surface

Given that lead wires for the gages cannot be readily strapped down using spotwelded straps, adhesive bonding is to be utilized. The steps are as follows:

1. After determining lead wire routing along the surface of the test article, spots for securing the wiring to the surface should also be determined.
2. These spots should be masked to approximately 3/8" in diameter.
3. Micro-sandblast these spots with the 50 micron abrasive powder.
4. Next, remove the masking tape and eliminate any sandblast residue using clean, dry shop air.

Follow this with a spray cleaning of the areas once more with the degreaser.

5. Now, apply a coat of Omega CC ceramic cement around the diameter of the Nextel overbraid on the lead wires at the spots where the lead wires are to be secured to the surface. Cure the coating at 225°F for 15 minutes followed by 1 hour at 300°F.
   NOTE: The Omega CC serves as an insulator between the lead wires and the LEX-10, in that, its leakage resistance to ground is higher than that of LEX-10 and it provides a degree of protection from corrosive action between the LEX-10 and the Hoskins 875 lead wires.
6. While the lead wire coating is curing, apply a coat of LEX-10 cement to the surface on the sandblasted spots. This coating should be approximately .001" thick. Allow this to air dry for 1 hour, then, cure at 300°F for 1 hour.
7. Now, place the lead wires on the test article surface such that the Omega CC coating is over the LEX-10 spots. Cover the lead wires in these areas with another coat of LEX-10. Allow to air dry for 1 hour, then, cure at 300°F for 1 hour.
   NOTE: All gage installations should be completed before commencing the lead wire hold-down procedure.

Lead Wire Connection: Lead wire connection involves many tasks in preparing the exit lead wiring and the strain gage leads (or ribbons) for the spotwelding operations that are typically used in high-temperature strain gage electrical connections. Variables in the spotwelder probes and the spotwelder operational functions also play a role in determining just how the junction between the gage lead and the exit lead will be facilitated. Therefore, detailed procedures for high-temperature lead wire hook-up are not offered here.

INSTALLATION TYPE 4 - The following materials and procedures are applicable for Coarse Surface Ceramic Based Composites with Most Free-filament Gages

Gaging Materials (all materials that are an integral part of the test article)

1. Gage types: only restrictions are that gages should be at least 1/4" active grid length and that gages should be 2 mil diameter, minimum (this of course precludes the use of foil-type high-temperature gages)
2. Ceramic cement Basecoat, type: LEX-10 (Hitec Products)
3. Aluminum Oxide powder (Al_2O_3), (Hitec Products)
4. Lead wire hold-down adhesives, type: LEX-10 (Hitec Products) and type: Omega CC (Omega Engineering)
5. Lead Wires, type: Hoskins Alloy #875, AWG #25, 3-conductor with Nextel 312 sleeving over each conductor plus a Nextel 312 overbraiding over all three conductors (Santa Fe Textiles)

Gage Installation Procedure

NOTE: The gaging procedures described in the first two "installation types" can be used as a guide for installing high-temperature gages on this type of composite material. However, there are two areas involved in the installation that must be approached differently. One area is the surface preparation; the other is the attachment of the lead wires. Each is described here in detail.

Surface Preparation and Basecoat Installation

1. Spray clean all areas where gages are to be placed using a mild degreaser such as Micro-Measurements, FTF-1 solvent. Also, spray clean all areas where lead wires will be secured to the test article surface.
2. Mask the areas where gages are to be located and the spots where lead wires are to be adhesively bonded to the surface (see details below).
3. Sandblast the masked areas where gages are to be installed using #30 grit silicon/carbide abrasive powder. Do not allow the sandblast abrasive to dwell on an area more than a few seconds in order to avoid removing too much of the coarseness from the surface.
4. The basecoat for the gages on these coarse surface ceramic composites require a combination of ceramic cement followed by plasma sprayed Al_2O_3. The first material to be applied as part of the basecoat is LEX-10 cement. The coarseness of the surface will determine how many layers of this coating will be required. Each coating layer is to be installed as per the next two steps.
5. Apply a coating of LEX-10 to the sandblasted areas, approximately .002" thick. Allow this to air dry for one-half hour, take it up to 225° F and hold for another one-half hour. Then, take this coating up to 300° F and hold for one hour.
6. If the surface is still too rough for the flame spray operations, apply another coating of the LEX-10 as in the step above.
7. After the appropriate number of layers of LEX-10 has been applied, hone the cement in order to make the surface ready for the flame spray operations.
8. Plasma spray the LEX-10 with Al_2O_3 until a coating of approximately .002" in thickness has been achieved. This combination of ceramic cement and aluminum oxide powder serves as the basecoat. The installation of the gage can now be accomplished using "INSTALLATION TYPE 1" and "INSTALLATION TYPE 2" gaging procedures in this application class as a guide.
9. The lead wires require a basecoat, also. This is to be a ceramic cement. The installation of that basecoat and the lead wires is described below.

Lead Wire Hold-down to Surface

Given that lead wires for the gages cannot be strapped down using spotwelded straps, adhesive bonding is to be utilized. The steps are as follows:

1. After determining lead wire routing along the surface of the test article, spots for securing the wiring to the surface should also be determined.
2. These spots should be masked to approximately 3/8" in diameter.
3. Sandblast these spots with the #30 grit SiC abrasive.
4. Next, remove the masking tape and eliminate any sandblast residue using clean, dry shop air. Follow this with a spray cleaning of the areas once more with the degreaser.
5. Now, apply a coat of Omega CC ceramic cement around the diameter of the Nextel overbraid on the lead wires at the spots where the lead wires are to be secured to the surface. Cure the coating at 225° F for 15 minutes followed by 1 hour at 300° F.
   NOTE: The Omega CC serves as an insulator between the lead wires and the LEX-10, in that, its leakage resistance to ground is higher than that of LEX-10 and it provides a degree of protection from corrosive action between the LEX-10 and the Hoskins 875 lead wires.
6. While the lead wire coating is curing, apply a coat of LEX-10 cement to the surface on the sandblasted spots. This coating should be approximately .001" thick. Allow this to air dry for 1 hour, then, cure at 300° F for 1 hour.
7. Now, place the lead wires on the surface with the Omega CC coating over the LEX-10 spots. Cover the lead wires in these areas with another coat of LEX-10. Allow to air dry for 1 hour, then, cure at 300° F for 1 hour.
   NOTE: All gage installations should be completed before commencing the lead wire hold-down

procedure.

NOTE: Lead Wire Connection: Lead wire connection involves many tasks in preparing the exit lead wiring and the strain gage leads (or ribbons) for the spotwelding operations that are typically used in high-temperature strain gage electrical connections. Variables in the spotwelder probes and the spotwelder operational functions also play a role in determining just how the junction between the gage lead and the exit lead will be facilitated. Therefore, detailed procedures for high-temperature lead wire hook-up are not offered here.

APPLICATION CLASS V - GAGE INSTALLATION PROCEDURES FOR NON-TYPICAL OR UNIQUE MATERIALS OR TEST CONDITIONS (NOT COVERED UNDER APPLICATION CLASSES I THROUGH IV)

NOTE: Application Class V details gaging procedures for non-typical or unique strain gage application requirements. This class is added to provide recommended procedures and/or materials for gaging situations which are not routinely encountered, but ones which are likely to be encountered again in future applications.

INSTALLATION TYPE 1 - The following materials and procedures are applicable for gaging Aluminum/Lithium for Room Temperature and Cryogenic (to -320°F) Testing

NOTE: The following materials and procedures are applicable for aluminum/lithium test articles that are to be tested at temperatures ranging from room temperature down to -320°F. These materials and procedures assume that elevated temperature curing of gaging adhesives is **prohibited**. As always, there may be exceptions to the stated installation procedures. The testing parameters will dictate the gages, adhesives, moisture-barriers, etc., best suited to a particular task. **All of the test conditions must be reviewed with the test engineer** prior to commencing strain gage related efforts.

Gaging Materials (all materials that are an integral part of the strain gaged test article

1. Gage type: to be designated by test engineer, typically CEA series for room temperature testing and SK or WK series (Micro-Measurements) for cryogenic testing
2. Adhesive type: M-Bond AE-10 (Micro-Measurements)
3. Wiring Terminals type (when needed): CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of gages will determine which size is appropriate
4. Gage-to-Terminal Jumper Wire (when required): AWG#38 silver-clad copper
5. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor flat ribbon, AWG#30. For cryogenic testing, leadwires must be teflon insulated.
6. Solder type: 361-A (Micro-Measurements)
7. Protective Gage-coating type: wide variation depending on testing parameters-must be determined for each task

Surface Preparation for Gaging

1. Clean the areas to be gaged by wiping them with ENSOLV. Be careful not to bring surface contaminants back into the previously wiped areas by wiping through those areas from adjacent areas with a second wiping.
2. Perform microscopic examination of test article looking for surface flaws and other anomalies.
3. Again, wipe areas to be gaged with ENSOLV. Be careful not to bring surface contaminants back into the initially wiped areas.
4. Mask appropriate areas to be gaged and micro-sandblast using 50 micron abrasive powder.
5. Remove masking tape.
6. Wipe areas to be gaged using ENSOLV as in Step 3.
7. Finally, wipe areas as in Step 3 and Step 6 using alcohol. Application of the strain gage adhesive

should begin immediately following this step.

Installation of the Gages

NOTE: The following strain gage installation procedure is applicable for both short-term and long-term testing for this material within the scope of this "INSTALLATION TYPE 1" instruction. Through use, laboratory testing, and review with the Marshall Space Center's strain gaging group, it has been determined that methyl-cyanoacrylate adhesives, including M-BOND 200, does not provide sufficient bonding strength for use with strain gages on aluminum/lithium. Also, through laboratory testing, it has been verified that AE-10 Adhesive bonds well enough to measure strains up to 15,000 micro-strain on this material. The following steps are applicable for using AE-10 on aluminum/lithium test articles when elevated temperature curing of adhesives is not permitted and testing temperatures range from room temperature down to -320° F.

1. Gages and terminals (when used) should be cleaned with pure alcohol, dried, and placed on a clean glass plate, inverted and ready for installation.
2. Apply a coat of AE-10 to the underside of the gages and terminals to be installed as well as a coat to the appropriate test article surfaces.
3. Place the gages and terminals on the aluminum/lithium surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape.
4. Next, place silicone rubber pads over the tape in the areas where the gages are located.
5. Apply a constant and uniform pressure of 15 psi to the rubber pads using an appropriate clamping device.
6. Place the test article in a temperature chamber and raise the temperature to 100° F.
   NOTE: If the test engineer cannot allow the test article to be warmed to this temperature, then, the gage installation must be cured overnight at a minimum temperature of 80° F.
7. Hold the gaged test article at 100° F for a minimum of four hours.
8. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installation for accuracy of alignment, glue-line voids, or foreign matter.
9. When more than one cure cycle is required to complete all gage installations on a test article, the gage areas still requiring gages should be micro-sandblasted again with a repeat of the surface preparation steps previously outlined.

Wiring the Aluminum/Lithium Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage to two decimal places at the gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals.
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these gages should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
4. Using a soft brush and Borothene, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage to two decimal places at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. All intrabridge (when required) and interbridge (when required) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.

7. When possible, all intrabridge wires (when required) should be of equal resistance and length.
8. Wire routing should be preplanned with no wiring to be routed over the strain gage active grids or the gage jumpers.
9. When all wiring is completed, the test article should be cleaned to remove all soldering residues and other foreign matter.
10. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
11. If wired as bridges, check to confirm that the zeros are representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit.
12. Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure

Depending on the testing parameters, moisture protection may or may not be needed. Many factors must be reviewed in order to provide the appropriate coating over strain gage installations. Factors such as range of temperature the gages will encounter during testing, amount of moisture to be encountered, reinforcing effect on thin surfaces to be strained, short-term or long-term testing, and others must be weighed. Because gage coatings are custom-matched to the task, no particular moisture-proofing procedure is detailed here.

INSTALLATION TYPE 2 - The following materials and procedures are offered for installation of strain gages on INTERIOR SURFACES OF WIND TUNNEL MODELS where cryogenic temperatures down to -275° F may be encountered and where application of a "body filler" for achieving aerodynamic surfacing is required. The maximum elevated operating temperature for this procedure is 180° F

NOTE: The following materials and procedures are applicable for gaging NTF-type models on interior surfaces (typically wings) in which the surfaces to be gaged are made of a maraging steel. As always, there may be exceptions to the stated installation procedures. **All of the test conditions must be reviewed with the test engineer** prior to commencing strain gage related efforts.

Gaging Materials (all materials that are an integral part of the strain gaged test article

1. Gage type: to be designated by test engineer, typically WK or SK series (Micro-Measurements)
   NOTE: type: WK-06-060BN-350 w/option W has been tested and works well
2. Adhesive type: M-BOND GA-2 or M-BOND AE-10 (Micro-Measurements).
   NOTE: M-BOND GA-2 has been tested and works well
3. Wiring Terminals type (when needed): CPF-25C, CPF-38C, or CPF-50C (Micro-Measurements); size of gages will determine which size is appropriate
4. Gage-to-Terminal Jumper Wire (when required): AWG#38 silver-clad copper
5. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor, stranded, AWG#30, silver-plated copper. For Cryogenic testing, leadwires must be teflon insulated.
6. Solder type: 361-A (Micro-Measurements)
7. Materials to be used to cover the gage and fill the cavity for subsequent sanding and shaping to form aerodynamic surface are as follows: (a) Open-cell foam over gages, type: Insta-pak 200; (b) Structural adhesive over foam, type: Hysol 9309; (c) Structural adhesive w/carbon sphere-filler over

original structural adhesive; for this, the adhesive is type: Hysol 9309; the carbon spheres are type: S-100 (CarboSpheres)

Surface Preparation for Gaging

1. Clean the areas to be gaged with ENSOLV. Be careful not to wash surface contaminants back into the previously cleaned areas.
2. Perform microscopic examination of the strain gage areas of the test article. Look for surface flaws and other anomalies.
3. Again, clean areas to be gaged with ENSOLV. Be careful not to bring surface contaminants back into the previously cleaned areas.
4. Mask appropriate areas to be gaged. Be careful to protect the rest of the model from any residual aluminum-oxide sandblast powder.
5. Micro-sandblast using 50 micron abrasive powder.
6. Remove masking tape.
7. To remove any residual sandblast powder, use dry shop air (or equivalent).
8. Clean areas to be gaged using ENSOLV as in Step 3.
9. Finally, to clean areas as in Step 3 and Step 6 use alcohol. Application of the strain gage adhesive should begin immediately following this step.

Installation of the Gages

1. Gages (and terminals when used) should be cleaned with pure alcohol, dried, placed inverted on a clean glass plate, and ready for installation.
2. Apply a coat of M-BOND GA-2 (or AE-10) to the underside of the gages and terminals to be installed as well as a coat to the appropriate test article surfaces.
3. Allow the items coated with the gaging adhesive to air dry at least five minutes at room temperature.
4. Place the gages and terminals on the test article surfaces at predetermined locations and cover with a thin, pressure-sensitive teflon tape or teflon sheet as appropriate.
5. Next, place silicone rubber pads over the tape in the areas where the gages are located.
6. Apply a constant and uniform pressure of 10 psi to the rubber pads using an appropriate clamping device.
7. Allow the installed gages on the test article to cure a minimum of 6 hours at a minimum temperature of 125°F. If permitted, an elevated temperature cure of 4 hours at 150°F is sufficient.
8. Remove the clamping device, the rubber pads, and the tape. Inspect the gage installation for accuracy of alignment, glue-line voids, or foreign matter.
9. Post cure the installation for 8 hours at a minimum temperature of 125°F prior to the filling of the cavity. If permitted, an elevated temperature cure of 6 hours at 150°F, or, 2 hours at 200°F is sufficient.

Wiring the NTF Model Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. On a worksheet, record the resistance of each gage at the gage terminals or gage solder dots.
2. Using a hard rubber eraser, remove the oxidation from the CPF terminals when they are used..
3. Install and solder the gage jumpers between the gage dots and the wiring terminals. All soldering for these gages should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a

guide.

4. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage jumper wires.
5. On the worksheet, record the resistance of each gage at the wiring terminals. This will confirm the integrity of the jumper wires and the solder joints at the gage and the terminals.
6. Etch all strain gage leadwiring that is to be potted within the model cavity using Tetra-Etch (Micro-Measurements)
7. All intrabridge (when required) and interbridge (when required) wiring must be carefully stripped and tinned prior to installing at the terminals. Inspect for nicks in the strands before tinning.
8. When possible, all intrabridge wires (when required) should be of equal resistance and length.
9. Wire routing should be preplanned with no wiring to be routed over the strain gage active grids or the gage jumpers (when used).
10. When all wiring is completed, the test article should be cleaned to remove all soldering residues and other foreign matter.
11. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
12. If wired as bridges, check to confirm that the zeros are representative of the arbitrary differences in the resistances of the four gages that comprise the bridge circuit.
13. Check the resistance leakage to ground. This should be >10K Megohms.

Installation of Cavity Fillers over Strain Gage Areas

1. Once again, use alcohol to clean the cavity area that contains the strain gage and its ancillary wiring.
2. Apply the Insta-Pak 200 foam over the gage and solder joints in the cavity. This 2-part foam should be mixed with a one-to-one ratio, by weight, and quickly placed directly on the gage and terminal area.
   NOTE: This material should bond to the gage and its surrounding areas as the foaming action occurs.
3. The foam should be allowed to set un-disturbed for at least 2 hours.
4. Once the foam is set, it should be carefully trimmed (a scalpel works well) such that a coating is formed over the gage area of approximately 1/16" in thickness.
5. Next, the Hysol 9309 adhesive should be applied to the Insta-Pak 200 foam. This coating should be approximately 1/32" thick and it should cover all of the foam.
6. This coating should be cured for at least 4 hours at a minimum temperature of 75°F.
7. Finally, the Hysol 9309 with the S-100 CarboSpheres added (mixing ratio is 1.5 to 1 of carbon spheres to adhesive by weight), should be used to fill the remaining cavity area.
8. Fill the cavity sufficiently to require sanding for shaping and contouring to the model surface following curing of the adhesive.
9. Record final electrical checks to verify integrity of gage installation and coating.

INSTALLATION TYPE 3 - The following materials and procedures are applicable for gaging Titanium/Aluminum alloys for structural analysis or materials properties testing at temperatures ranging from -300°F to 650°F.

NOTE: This gaging procedure has not been validated through actual use. However, because of a pressing need to install gages on a Ti-6 test plate for immediate testing at these temperatures, the use

of this procedure has been initiated. The installation procedure described herein is currently being tested in the laboratory and, to date, the strain gage data look good. At these extreme temperatures the durability of the installation is a concern. In service, the number of cycles that this type of installation can withstand will depend on such parameters as maximum strains under the gage, how often the test article will get wet, the duration the test article will be temperature tested, the number of thermal cycles, the number of strain cycles, etc. The full capabilities of this procedure on this material at the stated temperatures are still being determined.

Gaging Materials (all materials that are an integral part of the strain gaged test article

1. Gage type: to be designated by test engineer, typically WK series (Micro-Measurements)
2. Wiring terminals, type: TL-56 (BLH)
3. Adhesive type: PLD-700 (BLH)
4. Strain Gage Leadwires type and length: specified by test engineer; currently using 326-GJF (Micro-Measurements)
5. Solder type: .031" Gold alloy spheres/770°F (Clad Metals) NOTE: these spheres are composed of 81.5%Au; 8.5%Ag; 10%Ge and have a melting temperature of 770°F
6. Thermocouples type (when needed): currently using INC--E-MO-062 (Omega)
7. Moisture barrier for gages, type: RTV-159 (General Electric); NOTE: this material is also to be used for leadwire hold-down on the test article

Surface Preparation for Gaging

1. Clean the areas to be gaged by wiping them with ENSOLV. Be careful not to bring surface contaminants back into the previously wiped areas by wiping through those areas from adjacent areas with a second wiping.
2. Perform microscopic examination of test article. Look for surface flaws and other anomalies.
3. Again, wipe areas to be gaged with ENSOLV. Be careful not to bring surface contaminants back into the initially wiped areas.
4. Mask appropriate areas to be gaged and micro-sandblast using 50 micron abrasive powder.
5. Remove masking tape.
6. Use ENSOLV as in Step 3 to wipe areas to be gaged.
7. Finally, use alcohol to wipe areas as in Step 3 and Step 6. Application of the strain gage adhesive should begin immediately following this step.

Installation of the Gages

1. Gages and terminals should be cleaned with pure alcohol, dried, and placed inverted on a clean glass plate, ready for installation.
2. With the test article also cleaned, the gage installation and heat curing steps should begin immediately as per the manufacturer's instructions for using PLD-700.
3. Once the heat cure is completed and cooled, remove the clamping device, the rubber pads, and the tape. Inspect the gage installation for accuracy of alignment, glue-line voids, or foreign matter.
4. When more than one cure cycle is required to complete all gage installations on a test article, the gage areas still requiring gages should be micro-sandblasted again with a repeat of the surface preparation steps previously outlined.
5. Post cure the gages at 700°F for 30 minutes once all installations are complete.

Wiring the Titanium/Aluminum Test Article

NOTE: Because of the considerable variation in test requirements it is not possible to itemize and

detail a standard wiring procedure for all Langley test articles. Nonetheless, certain steps can be detailed while others are generalized. The steps below are provided only as a "good practice" guide.

1. Following removal of the oxidation from the gage ribbons and the copper on the CTF terminals, solder the gage ribbons to the wiring terminals. All soldering for these gages should be performed using the NASA soldering handbook "NHB 5300.4(3A-1)" as a guide.
2. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage ribbons.
3. On a worksheet, record the resistance of each gage to two decimal places at the wiring terminals.
4. Install the three-wire, strain gage leadwires and solder to the gage wiring terminals.
5. Using a soft brush and ENSOLV, remove the flux residue from the solder joints and the gage wiring terminals.
6. On the worksheet, record the resistance of each gage at the end of the leadwires to verify that the total resistance is appropriate for this particular gage and leadwire system.
7. When all wiring is completed, the test article should be cleaned to remove all soldering residues and other foreign matter.
8. Check the resistance leakage to ground. This should be >10K Megohms.

NOTE: The RTV-159 that is to be used as a moisture-barrier for the solder joints and gage ribbons is also to be used for leadwire hold-down. Areas to receive the RTV-159 are to be lightly micro-sandblasted and cleaned prior to application of the RTV. The RTV should be kept at a minimum height over the wiring in order to prevent it from cracking during cryogenic excursions.

Moisture-Proofing Procedure

1. Use pure alcohol to clean all areas that are to be covered with the RTV-159.
2. Apply a coat of RTV-159 (approx. .050" thick) over the gage terminals, solder joints, and gage ribbons. Do not allow any of the moisture-barrier to be on the active area of the gage. This should be done with the test article and the RTV at a minimum temperature of 72°F and the relative humidity not more than 40 percent. Allow to air dry overnight before testing.

INSTALLATION TYPE 4 - The following materials and procedures are applicable for gaging ADHESIVE/POLYMER BASED COMPOSITES for structural analysis or materials properties testing up to 450°F

NOTE: Once again, there isn't a singular gage installation procedure that can be utilized universally for all elevated temperature testing with this class of composites. Often, the project engineer will restrict the temperature allowable in applying and curing the strain gage adhesive. The following gaging procedure has been utilized at Langley with a high degree of success for testing composites at temperatures up to 450°F when the allowable cure temperature for the gaging adhesive has been limited to 250°F.

Gaging Materials (all materials that are an integral part of the strain gaged composite)

1. Gage type: to be designated by test engineer, typically WK series (Micro-Measurements)
2. Adhesive type: M-Bond 600 (Micro-Measurements) *see note below
3. Wiring Terminals type: CPF series (Micro-Measurements)

4. Strain Gage Leadwires type and length: specified by test engineer; typically wiring is 3-conductor, size AWG#30, stranded (7-38), silver-plated copper with a teflon insulation over each conductor, either twisted or flat ribbon
5. Solder type: 570-28R (Micro-Measurements)
6. Protective Gage Coating type: typically not required; when required, 3140 RTV (Micro-Measurements) or RTV-159 (General Electric) are good choices

Surface Preparation for Gaging

1. Perform general degreasing and cleaning of the surface(s) to be gaged using 200 proof alcohol.
2. Visually examine (microscopic when possible) the areas to be gaged checking for cracks, broken fibers, voids, etc.
3. Mask the areas to be gaged and micro-sandblast. Use 50 micron aluminum-oxide abrasive powder. Do not allow the abrasive to dwell on an area more than a few seconds. This will prevent the sandblast abrasive from removing too much surface material.
4. Remove masking tape. Next, use dry shop air to remove abrasive powder residue.
5. Clean the surface again with 200 proof alcohol.
   NOTE: There are instances when the surfaces of these composites are too rough or too porous for installing strain gages. When this is encountered, a basecoat should be applied in the areas to be gaged. The following procedure works well.
6. Apply a basecoat of M-Bond 600 adhesive to the sandblasted areas. Allow to air dry at room temperature for 10 minutes.
7. Place a thin teflon sheet over the area, install a rubber pad over the teflon, clamp as you would if the strain gage were already in place, and apply a constant pressure of 30 psi.
8. Place the composite in the temperature chamber and raise the temperature to 250°F. The heating cycle should require at least 30 minutes to reach the curing temperature.
9. Cure the basecoat for one hour.
10. Following the basecoat cure, lightly micro-sandblast the basecoat.

Installation of the Gages

1. Areas to be gaged should be cleaned once again with 200 proof alcohol.
2. Make alignment marks in appropriate locations on the composite surface or the basecoat to coincide with the alignment marks around the four sides of the gage on the backing.
3. Each gage and wiring terminal to be installed should be placed on a clean glass plate, underside up. Coat the underside of the gage(s) and terminals and the surface basecoat with M-Bond 600 adhesive.
4. Allow to air dry at room temperature for at least 10 minutes, then, place the gages and terminals on the composite surfaces in the appropriate locations.
5. Next, a tape (CHR, Inc. type C) is applied to the top side of the gage and terminal.
6. Place a rubber pad over the tape and clamp as usual for M-Bond 600 maintaining a pressure on the installation at 30 psi.
7. Heat the composite to 250°F as before and hold at that temperature for 2 hours.
8. Cool the composite to room temperature and remove the clamp, pad, and tape.
9. DO NOT post cure.

Wiring the Gage

1. With a hard rubber eraser, remove any oxidation from the gage wiring terminal.
2. Check the gage resistance to verify that it is within the manufacturer's specifications.

3. Tin the wiring terminals and solder the gage ribbons to the terminals. Make certain that a mechanical strain relief is provided in the ribbons.
4. Strip both ends of the lead wires and check for nicks in the strands.
5. Tin the lead wires.
6. Secure the lead wires to the surface of the test article and solder the wires to the gage wiring terminals. Make certain that a mechanical strain relief is provided in the lead wires near the gage.
7. Remove flux residue from the solder joints.
8. Check the resistance at the end of the lead wires to verify that the total resistance is appropriate for this particular gage and lead wire system.
9. Check the resistance leakage to ground. This should be >10K Megohms.

Moisture-Proofing Procedure

Typically, no moisture-proofing applied to this type of installation. However, when one is required an RTV is usually sufficient (3140 RTV or RTV-159 works well). When a given test article is to be subjected to a more harsh environment, that environment will dictate the protective coating that is to be utilized. The various test scenarios requiring more elaborate coating schemes are too numerous to list here.

April 18, 1994

TO: 238/FSIS Technical Files
FROM: 238/Senior Aerospace Engineering Technician
SUBJECT: Matching Cryogenic Strain Gages

INTRODUCTION

There are inherent differences in the apparent strain curves of all transducer strain gages and since these differences are magnified at cryogenic temperatures, a resultant apparent strain is obtained when four of these strain gages are arbitrarily chosen and wired in a four-active arm Wheatstone bridge circuit. Therefore, it would be beneficial when designing cryogenic transducers with four active-arm strain gage bridges to have access to strain gages whose individual apparent strain curves are accurately predetermined and matched with respect to each other.

This matching of apparent strain curves is accomplished by means of a "temporary bonding technique" and through data comparison of a group of gages utilizing a computer program. The gages, following computer matching, will be disbonded and made ready for permanent installation.

This memorandum describes the "temporary bonding technique" and the steps utilized with the computer in the actual matching of the gages.

TEMPORARY BONDING TECHNIQUE FOR THE GAGES

(a) Gage Criteria - The gages to be temporarily bonded for matching should be one type and from one lot number. For cryogenic transducers, the gages typically will be Micro-Measurements type: C-891113-B. The optimum number of gages to be matched at one time with the current computer program is 16.
(b) Prior to installing the temporarily bonded gages, two strips of polyimide backing and 16 pairs of CPF-38C terminals are to be bonded to the gage matching disc as shown on the attached sketch. These are to be cured in place using standard installation procedures for Micro-Measurements M-BOND 610.
(c) With the polyimide strips and the terminals in place, micro-sandblast the disc surface in the areas where the gages are to be temporarily bonded. Place the gages in position as shown in the sketch and bond them to the surface using M-BOND 200. Standard Micro-Measurements procedures for this adhesive are applicable.
(d) Next, using Micro-Measurements solder type: 361-A, solder the "gage-to-terminal" jumper wires between the gage solder dots and the CPF terminals. The jumpers should be a single conductor of AWG #40 silver-clad copper, each equal in length and resistance. The external leads should be stranded AWG #32 silver-clad copper with teflon insulation and wired for 3-wire, quarter-bridge readout.
NOTE: The set-up and testing of the gages is described in the section that follows "Disbonding the Temporary Gages".

DISBONDING THE TEMPORARY GAGES

(a) After the 16 gages have been "matched", an elevated temperature cycle will be incorporated to affect the disbonding. The gaged disc should be placed in a temperature chamber . The temperature is then raised to 170°C and held for two hours. As the temperature approaches the 170°C level the gages disbond from the disc but remain suspended in place above the surface via the jumper wires that connect the gages to the lead wire terminals. During the two hours that the gages are soaking at the elevated temperature, the M-BOND 200 adhesive disintegrates leaving them virtually free of any material on the bottom side of the gage.
(b) Following the disbonding cycle the gages should be unsoldered from the jumper wires using a minimum amount of soldering iron tip heat. Next, each gage should be subjected to the following cleaning and surface preparation steps. 1. Flush each gage with Inhibisol; 2. Pumice the underside of each gage using S.S. White #3 grit powder; 3. Now, flush each gage with an ammonia base neutralizer followed with hot water; 4. Finish by flushing with 200 proof alcohol.
(c) After a microscopic examination of the underside of the gages to confirm there is no remaining residue, the gages should be cataloged for cryogenic transducer use as determined by the computer data that were generated during the gage matching run. (See the "Matching Apparent Strain Curves" section)

SET-UP AND TESTING OF THE GAGES

Following are the operating instructions for obtaining apparent strain data on 16 strain gages temporarily bonded to a metal disc as described above.

Equipment:
- Cryogenic Temperature Chamber
- 16 Bridge Completion Networks
- Temperature Readout for Type: T Thermocouple (Analog Output = 1mV/°C)
- 20 Channel Balance Calibration Data Acquisition System (DAS)

SET-UP:
Place the strain gaged disc in an enclosure within the chamber . Route prewired gages and the thermocouple through the side port. Plug the port. Connect the gages to the bridge completion unit and the bridge completion unit to the data acquisition. Connect the thermocouple to temperature readout #1. Place the completion unit where it will not be subjected to changing temperatures or air currents. Connect a cable from the top red (+) and black (-) Banana Jacks on the bridge completion unit to the voltage input XLR connector on the front of the DAS (pin #1+, pin #2-, pin #3 shield). Connect a cable from the same set of Banana Jacks to the voltage sense connector on the front of the DAS. Connect a cable from the lower set of Banana Jacks to the voltage monitor connector. Connect cables 1 through 16 coming from the side of the bridge completion unit to channels 1 through 16 on the front of the DAS.

INPUTING INFORMATION AND SIGNAL CHECKOUT:
Load the program. The screen will present questions that pertain to the test to be performed. Read the questions carefully. Type in the answer while watching the screen to be sure no mistake is made. If a mistake is made press the "clear" key in the top row of keys and re-enter the answer. When the instructions say "press key '1'", it is not referring to the number key 1 but to the special function keys 1 through 10 in the upper left-hand corner of the keyboard. After answering the "on screen" questions and before starting the test, the output of each channel should be reviewed with the voltmeter. Check

each reading for value and stability. The input voltage (channel 0) should be 5.000 volts. Channels 1 through 16 should be between -0.005 and 0.005. Channel 17 should indicate the temperature of the test block times 1000. For example, a voltmeter reading of 0.025100 is 25.1°C (0.025100 X 1000 = 25.1). Any unusual reading or instability should be investigated before start the gage matching test run.

DATA ACQUISITION:

After completion of the system checkout, data acquisition is commenced. Conduct the test as follows:

1) Press Key 2 which records an electrical zero at the current temperature and prints out the headings and the electrical zeros. Now it waits for the starting temperature that was input.
2) The chamber should be set to go to the end point temperature chosen for this test and turned on.
3) Data will now be taken automatically by the system at the desired temperature intervals.
4) The test manager should check the test periodically to make sure the temperature is changing as anticipated and that the data being generated is not erratic.
5) Once the end point temperature has been reached, the chamber should be reset to return to room temperature.
6) When the temperature readout indicates that the temperature is starting to increase, press Key 5. The system will take data at this end point and start taking data at the desired intervals during the return to room temperature.
7) When the test temperature increases from cryo to -10°C, turn off the power supply to keep the condensation that forms on the disc from shorting out the gages.
8) Press Key 6 to stop the test and store the data.

NOTE: Key 9 can be pressed to view a plot of the apparent strain curves.

MATCHING APPARENT STRAIN CURVES

Gages are matched in groups of four. The four gages that will comprise a group will be reviewed for magnitude of signal in three areas. They are; (1)maximum output throughout the temperature excursion, (2)loop data, which is defined as a difference in output at a given temperature comparing that output when the excursion is going cold versus going hot, (3)non-linearity. The maximum allowable outputs for each of the parameters would be +/-.015mV/5V. Potential matches can be reviewed on screen with final selections of matched groups being cataloged for use as active four-arm Wheatstone bridge circuits for cryogenic transducers including wind tunnel balances.

Tom Moore
Strain Gage Testing and Development Laboratory
ETTD, Langley Research Center

GAGE MATCHING DISC
(FOR LARC CRYO BALANCES)

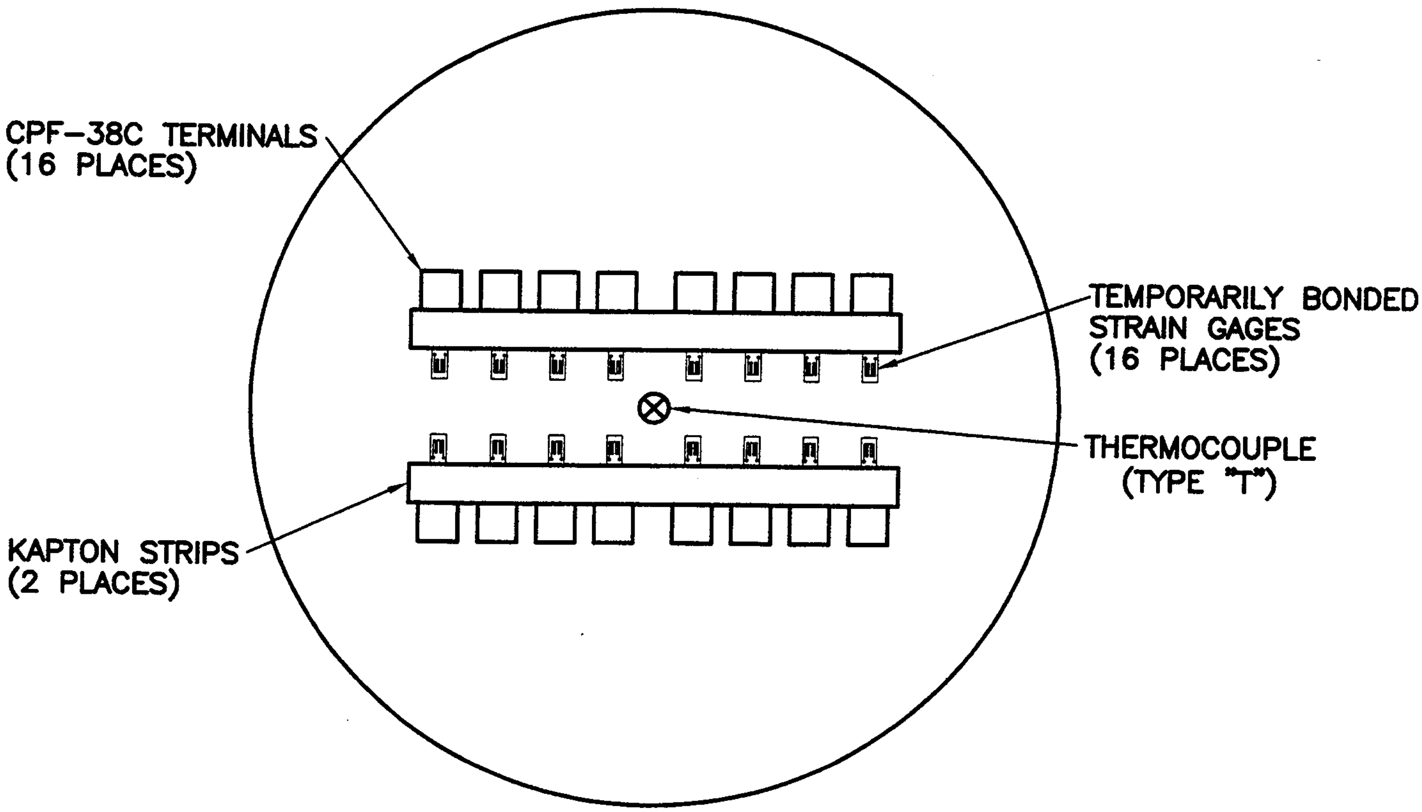

FIGURE 1

NOTES:

1) GAGES ARE "SK" SERIES.
2) KAPTON STRIPS ARE .2" X 2.5" X .002".
3) DISC IS 4" DIAMETER X 1" THICK.
4) TERMINALS AND KAPTON ARE BONDED WITH M-BOND 610.

Instructions for the Application of Micro-Measurements M-Bond 450 Adhesive

INTRODUCTION

M-Bond 450 is a high performance two-component solvent-thinned epoxy system specially formulated for strain gage use. It is capable of forming very strong, thin [down to 0.0001 in *(2.5 μm)*], repeatable bonds. M-Bond 450 is formulated especially for high accuracy, elevated temperature installations.

While M-Bond 450 is compatible with all Micro-Measurements strain gage series, it is especially compatible with J5K-Series gages. With this combination, it is possible to make high performance transducer installations capable of withstanding temperatures above +400°F *(+205°C)* for extended periods.

M-Bond 450 is a multi-stage epoxy system. Once the adhesive is brought to its B-stage (the stage of the polymerization cycle where the adhesive is dry and tack-free at room temperature, but is still fusible under heat and pressure), the adhesive may stand for extended periods until the final cure is initiated.

HANDLING PRECAUTIONS

M-Bond 450 is flammable in the uncured state. Do not use near sparks or flames. Epoxy resins may cause dermatitis or other allergic reactions, particularly in sensitive persons. The user is cautioned to: *Avoid contact with skin or mucous membranes; avoid prolonged or repeated breathing of vapors; and use the adhesive only in well-ventilated areas.* If skin contact occurs, immediately wash the affected area with soap and warm water. In case of eye contact, flush immediately with water and secure medical attention. As with all epoxy resin systems, rubber gloves, safety goggles, and aprons are recommended, and care should be taken to prevent contamination of working surfaces, tools, etc. Spills should be cleaned up immediately. For additional health and safety information, consult the Material Safety Data Sheet, which is available upon request.

OPERATING TEMPERATURE

Short Term:	–452° to +750°F *(–269° to +400°C)*
Long Term:	–452° to +500°F *(–269° to +260°C)*

ELONGATION CAPABILITY

Greater than 5% at +75°F *(+24°C)*.

SHELF LIFE

Six months at +75°F *(+24°C)*.

POT LIFE

Six weeks at +75°F *(+24°C)*.

MIXING M-BOND 450

M-Bond 450 is a two-component system supplied in premeasured quantities.

1. Parts A and B must be at room temperature before opening. Shake Part B vigorously for 10 seconds.
2. Using the disposable plastic funnel, empty contents of the bottle labeled "Part B" into the bottle of resin labeled "Part A". Discard funnel.
3. After tightening the brush cap provided, thoroughly mix the adhesive by vigorously shaking the bottle for 10 seconds.
4. Mark the date mixed in the space provided on the bottle.
5. **Allow the adhesive to stand for 24 hours at room temperature before using.**

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SURFACE PREPARATION

The extensive subject of surface preparation is covered in Instruction Bulletin B-129, *Surface Preparation for Strain Gage Bonding*. Transducer manufacturers using production line methods of surface preparation for adhesives such as M-Bond 600 or 610 may use the same methods for M-Bond 450.

GAGE INSTALLATION

Step 1

Prepare the surface of the specimen in accordance with ***Surface Preparation*** above.

Step 2

Apply a layer of adhesive on the component to be gaged, making certain to wet the entire area to be covered by the gage and/or terminal. Allow the installation to air dry for 10 to 30 minutes at +75° F *(+24° C)* and 50% relative humidity. Longer air-dry times may be necessary for lower temperature and/or higher humidities.

Step 3

Bring the adhesive layer to its B-stage by placing the test part in a cool oven and increasing the temperature to +225° F *(+105° C)* for 30 minutes. The oven temperature rise rate should be 5° to 20° F *(3° to 11° C)* per minute.

Note: Ideally, ovens used for gage bonding and postcuring should not be used for any other purpose. Forced-air ovens tend to circulate contaminants such as oils, carbonized particles, and dust. Since M-Bond 450 is exposed to the environment during its B-stage cycle, contaminants are likely to settle into the adhesive and cause bonding problems.

Once the adhesive has reached its B-stage, it is possible to store the component in a clean, dry place for up to one week without sacrificing final bond strength or repeatability. If there is a possibility that the B-staged adhesive layer has been exposed to a humid environment during storage, heat the component to +225° F *(+105° C)* for 10 minutes to expel any moisture that may have been absorbed.

Step 4

Clean a glass plate (or an empty gage box) and a pair of blunt-nosed tweezers with a gauze sponge and M-Prep Neutralizer 5. Remove a gage from its envelope by gently grasping the corner of the gage backing with the cleaned tweezers. Position the gage, bonding side down, on the cleaned work surface. The gage envelope may be used to temporarily hold the gage in position. Place a short length of MJG-2 Mylar tape over approximately half the gage tabs and the bondable terminal, if used.

Step 5

Remove the tape/gage assembly from the work surface by peeling the tape at a shallow angle (45° or less), and transfer it to the component surface. Do not apply additional adhesive. If misalignment occurs, lift the tape at a shallow angle and reposition the assembly. Make certain the entire area under the gage has been previously covered with the now B-staged adhesive.

Step 6

Overlay the gage area with a piece of Teflon film. If necessary, anchor the film in place with a piece of MJG-2 tape. Apply a 3/32 in *(2 mm)* thick silicone rubber pad and a metal backup plate which is slightly larger than the area covered by the gage.

Step 7

Clamp the installation by using dead weights, spring clamps, or other methods described in Micro-Measurements Tech Tip TT-610, *Strain Gage Clamping Techniques*. Recommended clamping pressure is 40 to 100 psi *(275 to 690 kN/m^2)*. Place the component in an oven and increase the temperature to +350° F *(+175° C)*. Cure for 1 hour. Temperature rise time is not critical.

Step 8

Upon completion of the curing cycle, allow the component to cool sufficiently and remove it from the oven. Unclamp the gages and remove the Mylar tape.

Step 9

For best performance, a postcure is recommended. It is desirable to postcure the installation after wiring; however, careful consideration must be given to the temperature limits of the leadwires and solder. Postcure the installation for at least 1 hour at a temperature at least 50° F *(28° C)* above the maximum operating temperature. The maximum postcure temperature should not exceed +550° F *(+290° C)*, and should be reached by going up in 50° F *(25° C)* steps from the +350° F *(+175° C)* cure temperature, dwelling 60 minutes at each step.

REFERENCES

Micro-Measurements Instruction Bulletin B-129, *Surface Preparation for Strain Gage Bonding.*

Micro-Measurements Instruction Bulletin B-130, *Strain Gage Installations with M-Bond 600 and 610 Adhesive Systems.*

Micro-Measurements Tech Tip TT-610, *Strain Gage Clamping Techniques.*

Strain Gage Installations with M-Bond 200 Adhesive

INTRODUCTION

Micro-Measurements Certified M-Bond 200 is an excellent general-purpose laboratory adhesive because of its fast room-temperature cure and ease of application. When properly handled and used with the appropriate strain gage, M-Bond 200 can be used for high-elongation tests in excess of 60 000 microstrain, for fatigue studies, and for one-cycle proof tests to over +200°F *(+95°C)* or below –300°F *(–185°C)*. The normal operating temperature range is –25° to +150°F *(–30° to +65°C)*. M-Bond 200 is compatible with all Micro-Measurements strain gages and most common structural materials. When bonding to plastics, it should be noted that for best performance the adhesive flowout should be kept to a minimum. For best reliability, it should be applied to surfaces between the temperatures of +70° and +85°F *(+20° to +30°C)*, and in a relative humidity environment of 30% to 65%. M-Bond 200 catalyst has been specially formulated to control the reactivity rate of this adhesive. The catalyst should be used sparingly for best results. Excessive catalyst can contribute many problems; e.g., poor bond strength, age-embrittlement of the adhesive, poor glueline thickness control, extended solvent evaporation time requirements, etc.

Since M-Bond 200 bonds are weakened by exposure to high humidity, adequate protective coatings are essential. This adhesive will gradually become harder and more brittle with time, particularly if exposed to elevated temperatures. For these reasons, M-Bond 200 is not generally recommended for installations exceeding one or two years.

For proper results, the procedures and techniques presented in this bulletin should be used with qualified Micro-Measurements installation accessory products (refer to Micro-Measurements Catalog A-110). *M-LINE* accessories used in this procedure are:

CSM-1A Degreaser or GC-6 Isopropyl Alcohol
Silicon Carbide Paper
***M-Prep* Conditioner A**
***M-Prep* Neutralizer 5A**
GSP-1 Gauze Sponges
CSP-1 Cotton Applicators
PCT-2A Cellophane Tape

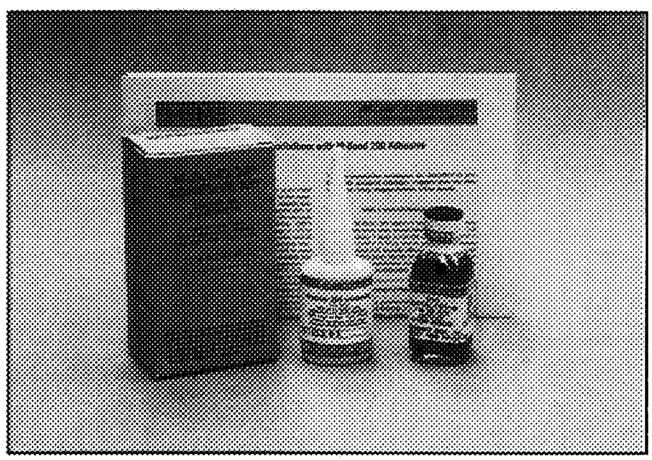
Various installation techniques are described on professionally prepared videotapes available from the Measurements Group. Request Bulletin 318 for details.

SHELF AND STORAGE LIFE

Unopened M-Bond 200 adhesive has a shelf life of nine months when stored under normal laboratory conditions. Life can be extended if upon receipt the *unopened* material is refrigerated [+40°F *(+5°C)*]. Due to possible condensation problems which will degrade adhesive performance, care should be taken to ensure that the M-Bond 200 has returned to room-temperature equilibrium before opening. Refrigeration after opening is not recommended.

HANDLING PRECAUTIONS

M-Bond 200 is a modified alkyl cyanoacrylate compound. *Immediate bonding of eye, skin or mouth may result upon contact. Causes irritation.* The user is cautioned to: (1) *avoid contact with skin;* (2) *avoid prolonged or repeated breathing of vapors;* and (3) *use with adequate ventilation.* For additional health and safety information, consult the Material Safety Data Sheet which is available upon request.



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GAGE APPLICATION TECHNIQUES

The installation procedure presented on this and the following pages is somewhat abbreviated and is intended only as a guide in achieving proper gage installation with M-Bond 200. *Micro-Measurements Instruction Bulletin B-129* presents recommended procedures for surface preparation, and lists specific considerations which are helpful when working with most common structural materials.

Fig. 1

Step 1

Thoroughly degrease the gaging area with solvent, such as CSM-1A Degreaser or GC-6 Isopropyl Alcohol (Fig. 1). The former is preferred, but there are some materials (e.g., titanium and many plastics) which react with chlorinated solvents. In these cases GC-6 Isopropyl Alcohol should be considered. All degreasing should be done with uncontaminated solvents — thus the use of "one-way" containers, such as aerosol cans, is highly advisable.

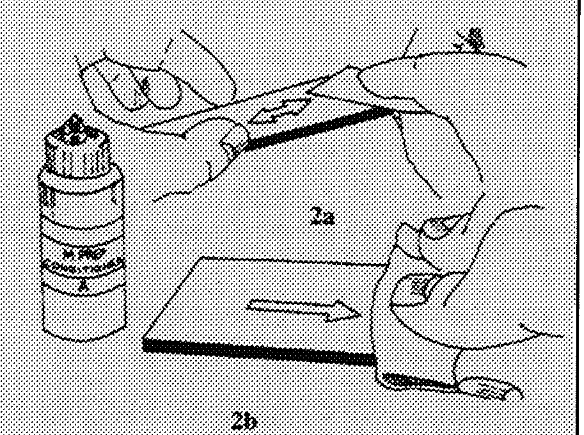


Fig. 2

Step 2

Preliminary dry abrading with 220- or 320-grit silicon-carbide paper (Fig. 2a) is generally required if there is any surface scale or oxide. Final abrading is done by using 320- or 400-grit silicon-carbide paper on surfaces thoroughly wetted with M-Prep Conditioner A; this is followed by wiping dry with a gauze sponge. Repeat this wet abrading process, then dry by slowly wiping through with a gauze sponge, as in Fig. 2b.

With a 4H pencil (on aluminum) or a ballpoint pen (on steel), burnish *(do not scribe)* whatever alignment marks are needed on the specimen. Repeatedly apply M-Prep Conditioner A and scrub with cotton-tipped applicators until a clean tip is no longer discolored. Remove all residue and Conditioner by again slowly wiping through with a gauze sponge. Never allow any solution to dry on the surface because this invariably leaves a contaminating film and reduces chances of a good bond.

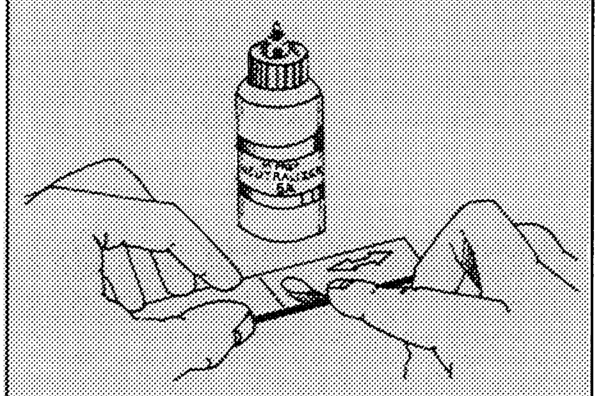


Fig. 3

Step 3

Now apply a liberal amount of M-Prep Neutralizer 5A and scrub with a cotton-tipped applicator. See Fig. 3. With a single, slow wiping motion of a gauze sponge, carefully dry this surface. Do not wipe back and forth because this may allow contaminants to be redeposited.

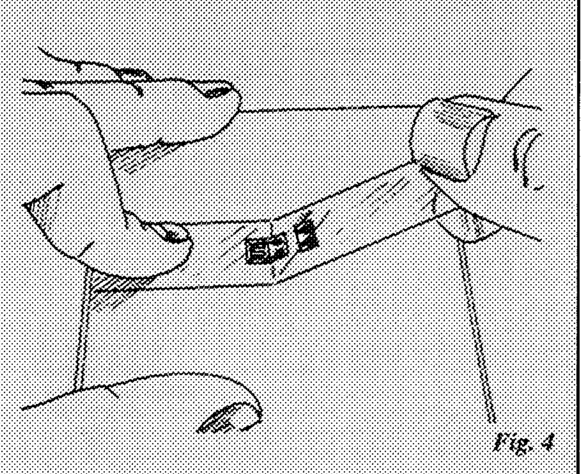


Fig. 4

Step 4

Using tweezers to remove the gage from the mylar envelope, place the gage (bonding side down) on a chemically clean glass plate or gage box surface. If a solder terminal is to be incorporated, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in *(1.6 mm)* should be left between the gage backing and terminal. Place a 4- to 6-in *(100- to 150-mm)* piece of Micro-Measurements No. PCT-2A cellophane tape over the gage and terminal. Take care to center the gage on the tape. Carefully lift the tape at a shallow angle (about 45 degrees to specimen surface), bringing the gage up with the tape as illustrated in Fig. 4.

Step 5

Position the gage/tape assembly so that the triangle alignment marks on the gage are over the layout lines on the specimen (Fig. 5). If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly, and firmly anchor down at least one end of the tape to the specimen. Realignment can be done without fear of contamination by the tape mastic if Micro-Measurements No. PCT-2A cellophane tape is used, because this tape will retain its mastic when removed.

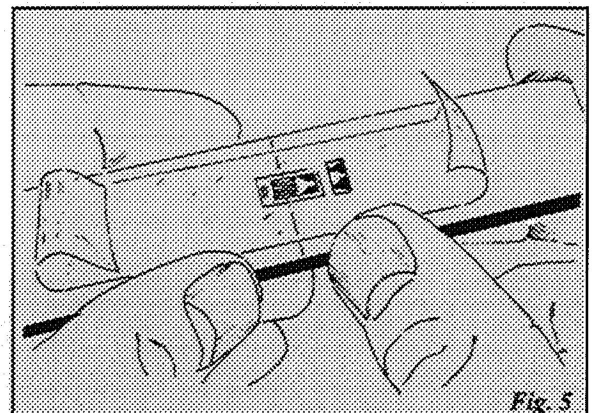


Fig. 5

Step 6

Lift the gage end of the tape assembly at a shallow angle to the specimen surface (about 45 degrees) until the gage and terminal are free of the specimen surface (Fig. 6a). Continue lifting the tape until it is free from the specimen approximately 1/2 in *(10 mm)* beyond the terminal. Tuck the loose end of the tape under and press to the specimen surface (Fig. 6b) so that the gage and terminal lie flat, with the bonding surface exposed.

Note: Micro-Measurements gages have been treated for optimum bonding conditions and require no pre-cleaning before use unless contaminated during handling. If contaminated, the back of any gage can be cleaned with a cotton-tipped applicator slightly moistened with M-Prep Neutralizer 5A.

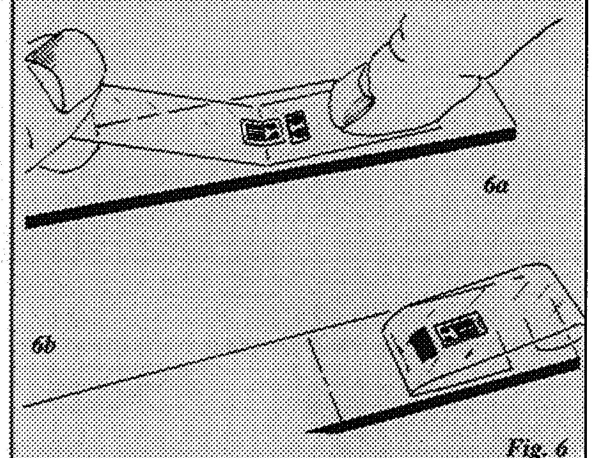


Fig. 6

Step 7

M-Bond 200 catalyst can now be applied to the bonding surface of the gage and terminal. M-Bond 200 adhesive will harden without the catalyst, but less quickly and reliably. Very little catalyst is needed and should be applied in a thin, uniform coat. Lift the brush-cap out of the catalyst bottle and wipe the brush approximately 10 strokes against the lip of the bottle to wring out most of the catalyst. Set the brush down on the gage and swab the gage backing (Fig. 7). Do not stroke the brush in a painting style, but slide the brush over the entire gage surface and then the terminal. Move the brush to the adjacent tape area prior to lifting from the surface. Allow the catalyst to dry at least one minute under normal ambient conditions of +75°F *(+24°C)* and 30% to 65% relative humidity before proceeding.

Note: The next three steps must be completed in the sequence shown, within 3 to 5 seconds. Read Steps 8, 9, and 10 before proceeding.

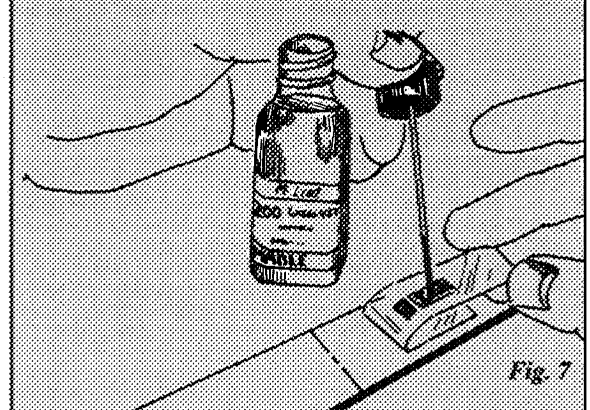


Fig. 7

Step 8

Lift the tucked-under tape end of the assembly, and, holding in the same position, apply one or two drops of M-Bond 200 adhesive at the fold formed by the junction of the tape and specimen surface (Fig. 8). This adhesive application should be approximately 1/2 in *(13 mm)* outside the actual gage installation area. This will insure that local polymerization, taking place when the adhesive comes in contact with the specimen surface, will not cause uneveness in the gage glueline.

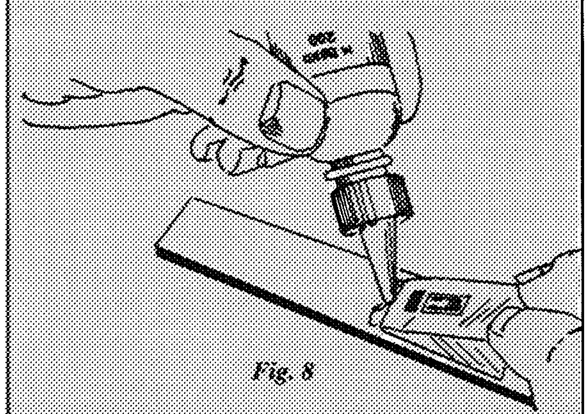


Fig. 8

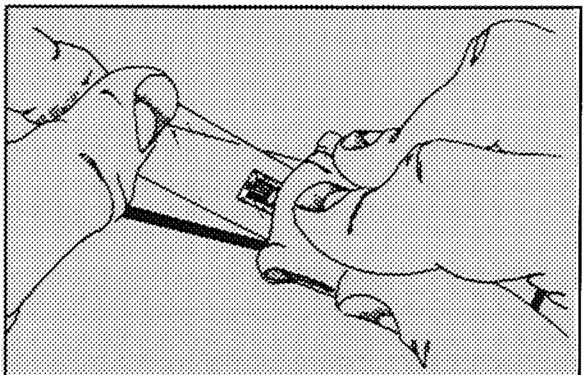


Fig. 9

Step 9

Immediately rotate the tape to approximately a 30-degree angle so that the gage is bridged over the installation area. While holding the tape slightly taut, slowly and *firmly* make a single wiping stroke over the gage/tape assembly with a piece of gauze (Fig. 9) bringing the gage back down over the alignment marks on the specimen. Use a firm pressure with your fingers when wiping over the gage. A very thin, uniform layer of adhesive is desired for optimum bond performance.

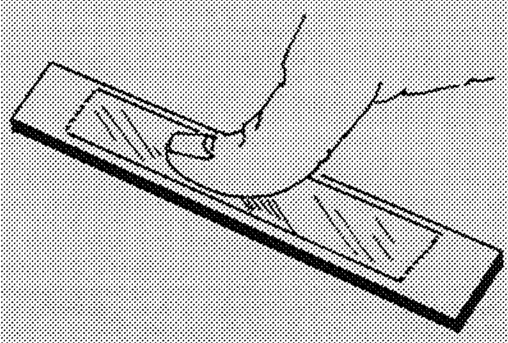


Fig. 10

Step 10

Immediately upon completion of wipe-out of the adhesive, firm thumb pressure must be applied to the gage and terminal area (Fig. 10). This pressure should be held for at least one minute. In low humidity conditions (below 30%) or if the ambient temperature is below +70°F *(+20°C)*, this pressure application time may have to be extended to several minutes. Where large gages are involved, or where curved surfaces such as fillets are encountered, it may be advantageous to use preformed pressure padding during the operation. Pressure-application time should again be extended due to the lack of "thumb heat" which helps to speed adhesive polymerization. Wait two minutes before removing tape.

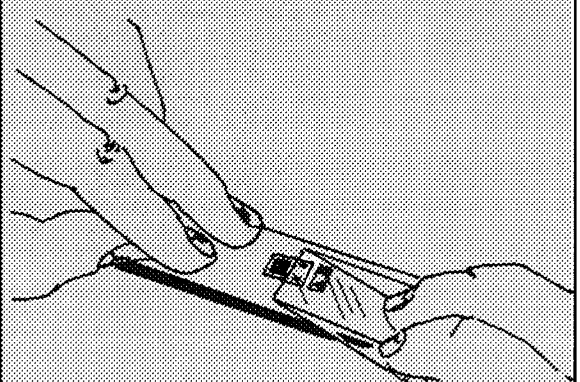


Fig. 11

Step 11

The gage and terminal strip are now solidly bonded in place. To remove the tape, pull it back directly over itself, peeling it slowly and steadily off the surface (Fig. 11). This technique will prevent possible lifting of the foil on open-faced gages or other damage to the installation. It is not necessary to remove the tape immediately after gage installation. The tape will offer mechanical protection for the grid surface and may be left in place until it is removed for gage wiring.

FINAL INSTALLATION PROCEDURE

1. Select appropriate solder, referring to *Micro-Measurements Catalog A-110,* and attach leadwires. Prior to any soldering operations, open-faced gage grids should be masked with PDT-1 drafting tape to prevent possible damage.
2. Remove the solder flux with *M-LINE* Rosin Solvent, RSK-1.
3. Select and apply protective coating according to the protective coating selection chart found in *Catalog A-110.*

STRAIN GAGE INSTALLATION PROCEDURE DEVELOPED FOR LARC GAGE TYPE: LARC-CKA1-1B

THIS PROCEDURE APPLICABLE FOR GAGING INCONEL 100 AND BETA 21S TMC

NOTE: Following is a detailed step-by-step procedure which has been developed and utilized for installing the subject compensated type strain gages on Inconel 100 and Beta 21S TMC surfaces. These procedures are written with the assumption that the user has access to plasma thermal spray hardware. The plasma spray step is considered optional and may be eliminated for most applications with these particular gages. However, it was observed, with limited lab testing, that maximum test temperature and strain range for the gages were obtained when the plasma spray system was utilized in conjunction with the oxygen/acetylene (Rokide) spray gun.

STEP 1: Locate the area where the strain gages are to be installed and clean with an appropriate degreaser. Measurements Group, Inc. spray cleaner, type: FTF-1, works well.

STEP 2: Mask around the area to be gaged using a tape that can withstand coarse grit sandblasting. The masking should provide an open area .6" wide by .7" long which is to be sandblasted. A high temperature fiberglass tape such as 3-M type: 64 works well.

STEP 3: Now micro-sandblast the open area within the masking using 50 micron Aluminum Oxide (Al_2O_3) abrasive powder. This step removes any surface coatings or surface oxidation which may be present. This step also provides a uniformly textured surface which is beneficial (visually) during the coarse sandblasting step.

STEP 4: Next, coarse sandblast the micro-sandblasted area with a #30 grit silicon carbide abrasive powder in order to generate a coarse texture for the thermal spraying operations that are to come later. Care must be exercised in this operation to keep the sandblasting at a minimum. Excessive passes with the sandblast gun could damage the surface of the area being textured.

STEP 5: After this, remove the masking tape and clean the area again with the FTF-1 spray cleaner. Follow this by swabbing the area with 200 proof grain alcohol.

STEP 6: Mask around the sandblasted area, again using the high temperature tape.

STEP 7: Set-up a system of compressed air adjacent to the area to be flame sprayed in order to provide a measure of cooling in this area during flame spray operations. Air pressure should be maintained at a low level to prevent disturbing the flow of molten aluminum oxide from the plasma or oxygen/acetylene flame spray gun.
NOTE: This compressed air is to be utilized for each flame spray operation throughout the remaining high temperature gaging steps listed here.

STEP 8: (Optional) Plasma spray a basecoat of Al_2O_3 to the sandblasted surface within the masked area. This first layer of gaging basecoat should be approximately .001" thick. This initial flame spray operation should take place within 30 minutes of the last sandblast operation.

STEP 9: To complete the basecoat, a second coat of Al_2O_3 is to be applied to the initial basecoat (STEP 8) using a Rokide flame spray gun. This layer of Al_2O_3 plus the original layer should total approximately .003" in thickness. (Photo #1)
NOTE: The initial basecoating step (STEP 8) utilizing the plasma sprayed Al_2O_3 is optional, but fewer gage failures on TMC have been observed at 1500 degrees F when this technique has been employed.

STEP 10: Next, position and secure the pair of gages (active and compensating), with their top carrier and sub carrier (Photo #2), to the basecoat.

STEP 11: At this point, the gage resistances should be checked and recorded.

STEP 12: Initial bonding of the exposed active gage convolutes, the exposed gage ribbons, and the exposed "tack-bond" areas of the compensating gage (Photo #3), should now be undertaken using a Rokide gun. Aluminum oxide rods (Norton type: SA) are to be utilized. Keep the amount of Al_2O_3 to a minimum. (Photo #4)

STEP 13: The next step is to carefully remove the top carrier and sub carrier tape segments from the active gage (Photo #5). With this done, inspect and remove any ridges of Al_2O_3 that may have formed adjacent to the carrier tape strips. An aluminum oxide abrasive stone or a pointed diamond file can be employed for this task. Photo #6 is a close-up of the gage now ready for final flame spraying of the active gage.

STEP 14: Final bonding of the active gage is next. The Rokide gun is again employed for this operation. Aluminum oxide rods of the same type that were utilized for the initial bonding of the gage convolutes is to be employed here. Flame spray all exposed areas making certain to cover the entire gage. Keep the total thickness to a minimum. Remember to use the compressed air to prevent the strain gage surface from overheating. A typical completed installation should be approximately .015" thick. Photo #7 shows the gage following final bonding of the active gage.

STEP 15: Remove the remaining top carrier being careful to insure that the sub carrier remains in place.

NOTE: Steps 16 through 20 are optional. These steps detail the requirements for adding a "window frame border" (Photos #8, #9, #10, #11) of aluminum oxide (Al_2O_3) around the entire installation for the purpose of minimizing the difference in temperature between the active gage and the compensating gage when air flows or fast heat-up rates are expected. This window frame border is actually a ridge of Al_2O_3 which forms a boundary for the thermal blanket.

STEP 16: Remove .100" of the sub carrier tape from the leadwire end of the gages. Also, remove .030" (this dimension may be revised depending on the overall width of the carrier tape furnished with the gages) from the remaining three sides (outside perimeter) of the sub carrier tape. This is done in order to expose the basecoat of Al_2O_3 and allows for the forming of the window frame border.

STEP 17: Next, add two layers of high temperature tape around the perimeter of the sub carrier tape leaving a .030" gap on all four sides. (Photos #8 & #9)

STEP 18: Add two layers of high temperature tape over the sub carrier tape, cut to the same size as the sub carrier tape. (Photos #8 & #9)

STEP 19: Using Rokide, flame spray the .030" perimeter gap until the Al_2O_3 fills the gap to the top of the tape. This completes the formation of the window frame border (ridge of Al_2O_3).

STEP 20: Remove all of the added tape being careful not to disturb the sub carrier tape. (Photos #10 & #11)

STEP 21: Now, carefully remove the individual segments of the sub carrier tape. Compensating gage convolutes must be kept flat against the basecoat. Photo #12 shows the installed gage after all tape has been removed. The installed gage elements are now ready for the thermal blanket which is shown adjacent to the gage.

STEP 22: Perform a final microscopic inspection of the installation. If no imperfections in the coating are observed, make another electrical check of the gage resistance and the gage resistance to ground. (Photo #13 - close-up of installed gage)

STEP 23: Install the thermal blanket (shown beside the gage in Photo #12) over both gage elements. The blanket should fit within the confines of the framing border (when framing border is utilized). The thermal blanket consists of a sheet of Nextel 312 cloth, .010" thick, which has had its top surface flame sprayed with a .005" thick layer of Al_2O_3. This sheet of Nextel is then cut to size to fit within the confines of the perimeter border.

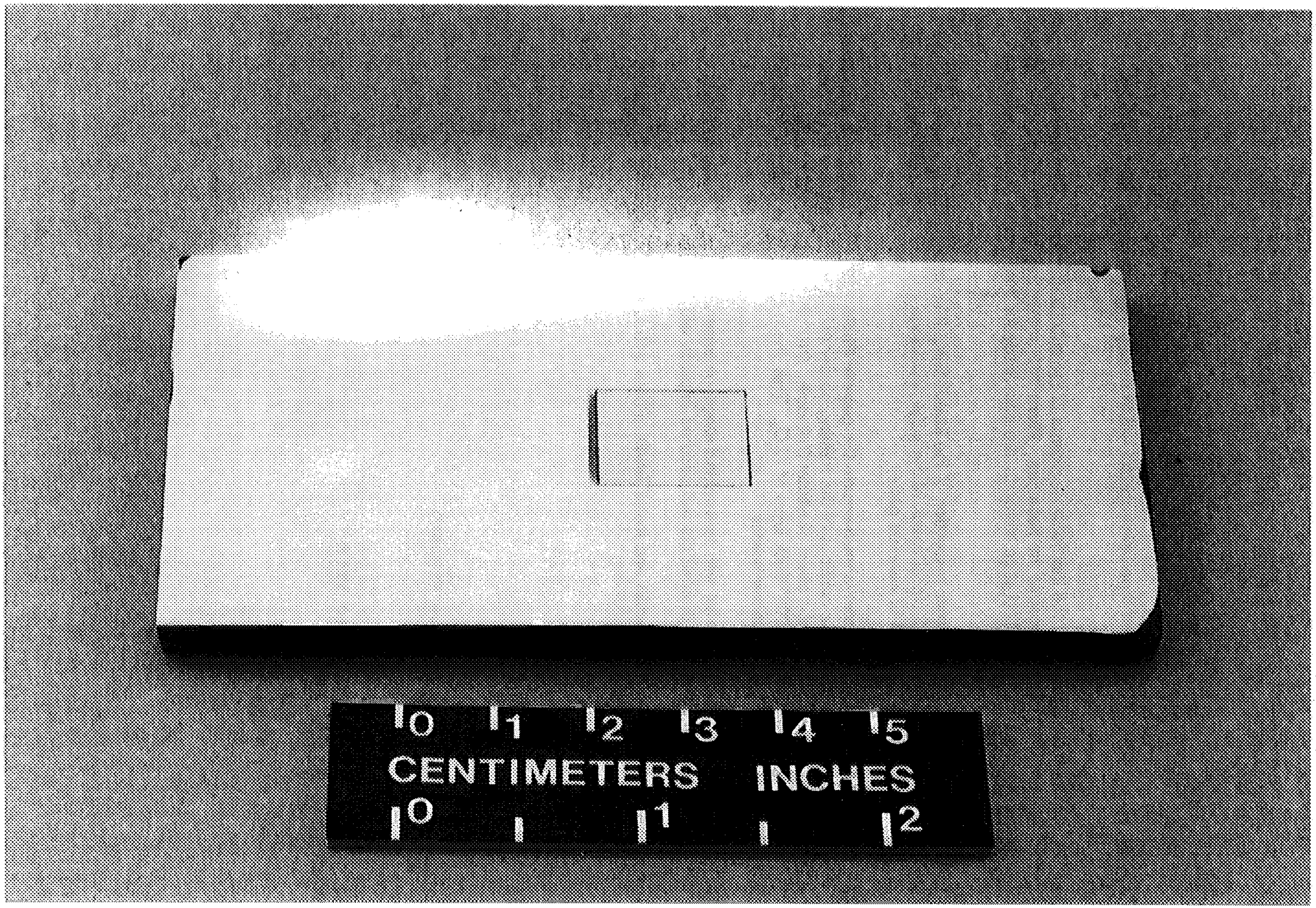
STEP 24: Secure the thermal blanket with spotwelded straps or ceramic cement. Photo #14 is a close-up showing the installed thermal blanket secured in place with straps.

STEP 25: Make final electrical checks and install leads. Photo #15 is an overview of a completed installation ready for leadwire hook-up.

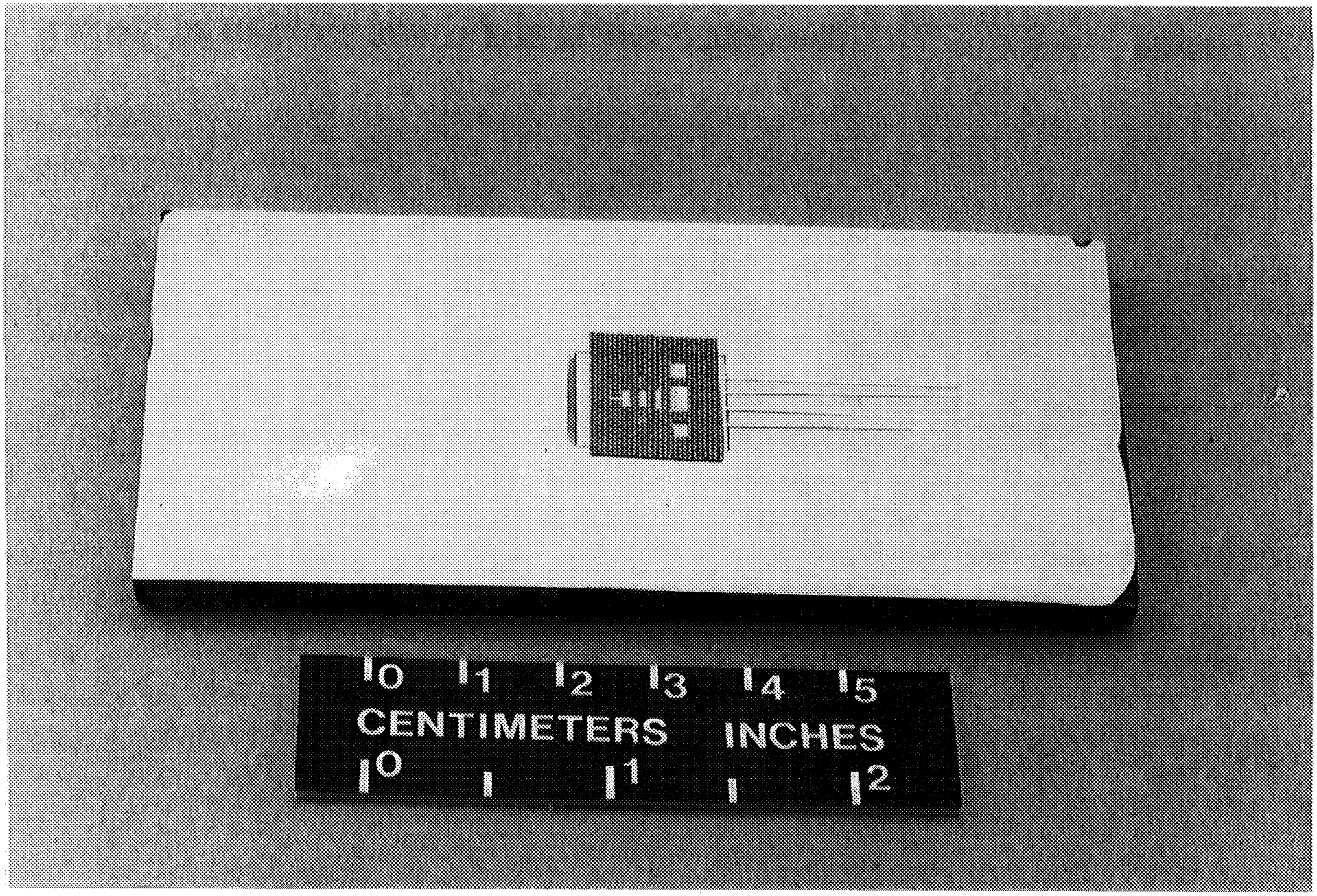
____________________Tom Moore, FSIS-IRD

____________________Fred Lamm, MM & T

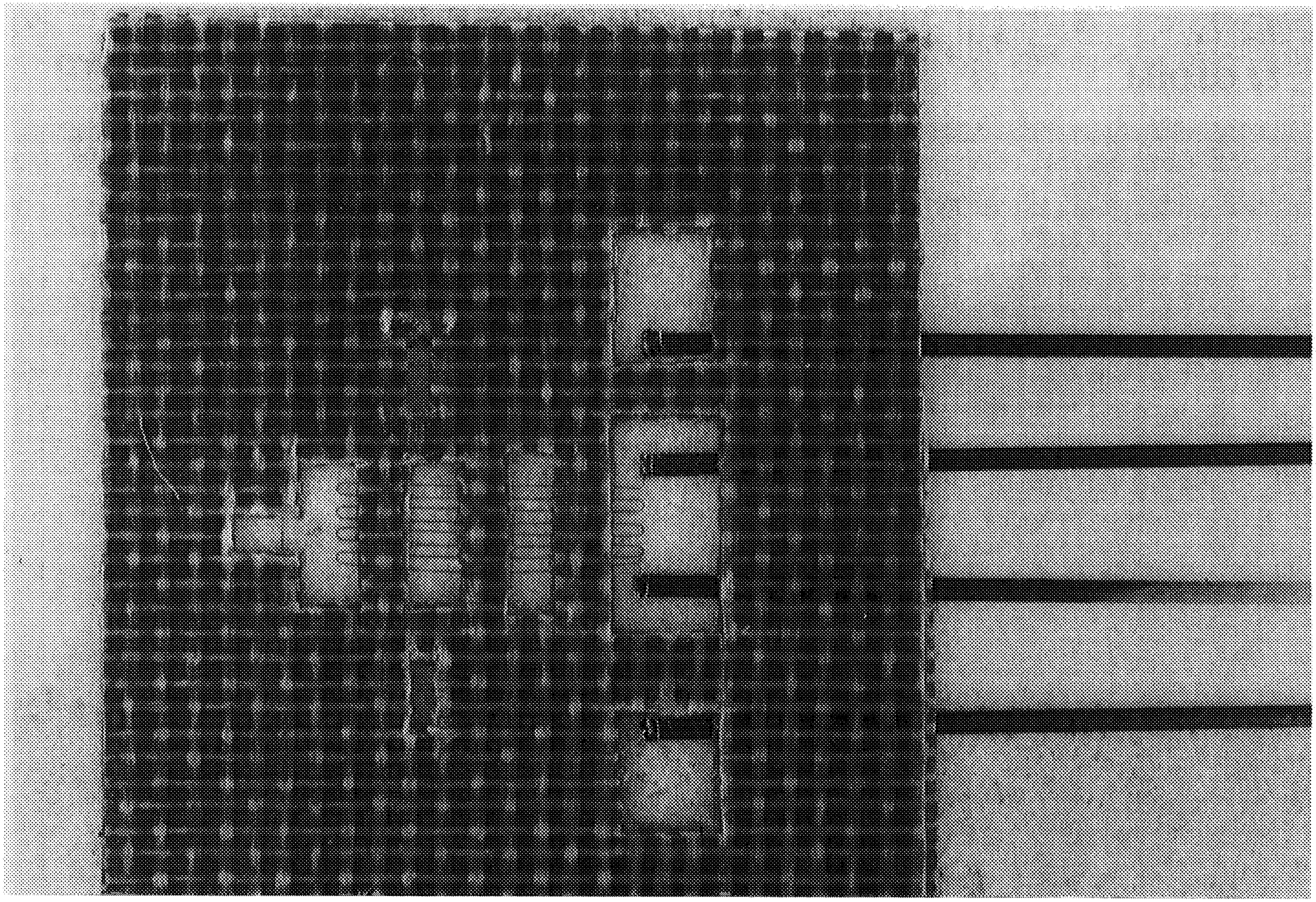
concur:



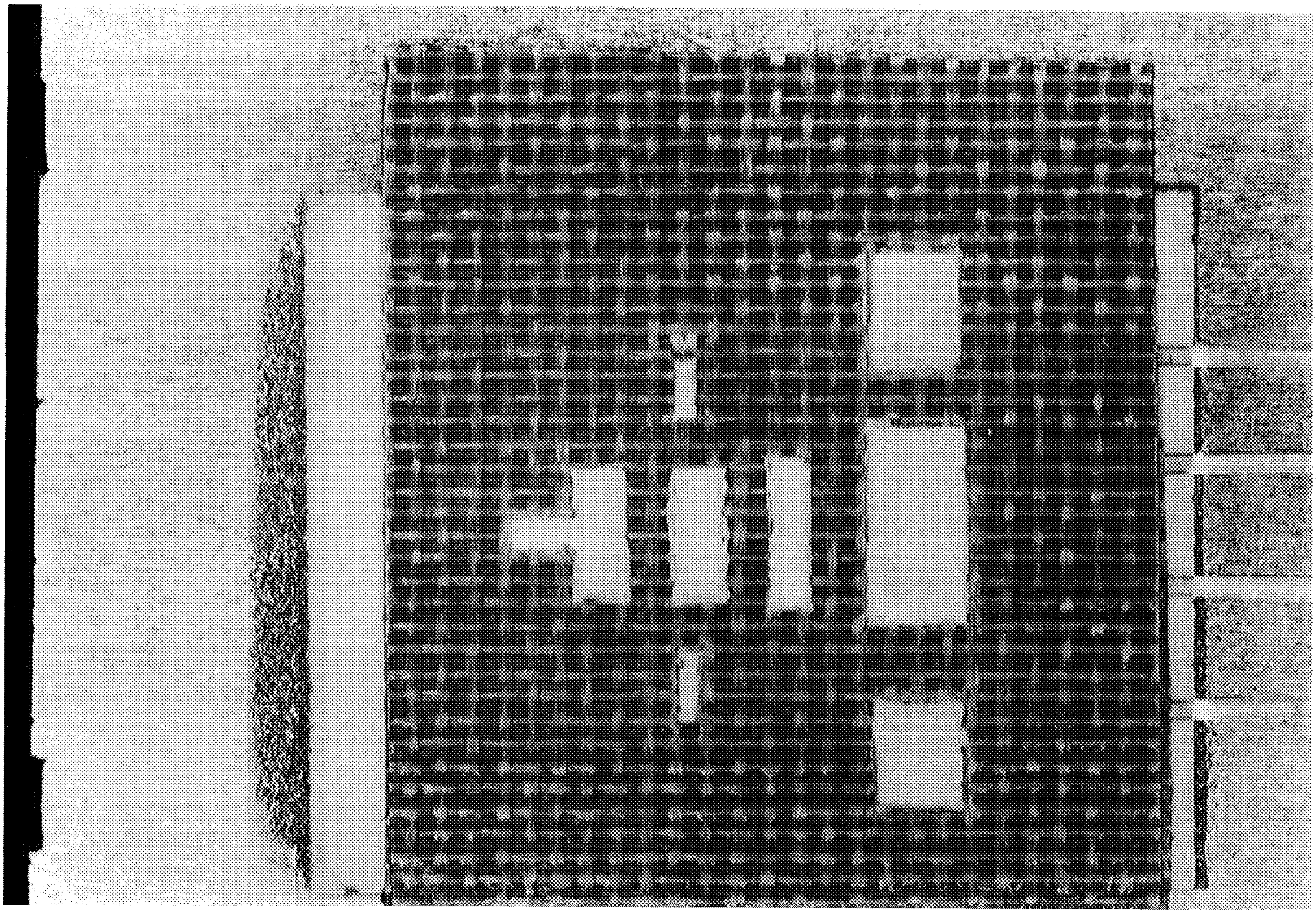
IN-100 TEST COUPON W/Al2O3 BASECOAT **PHOTO #1**



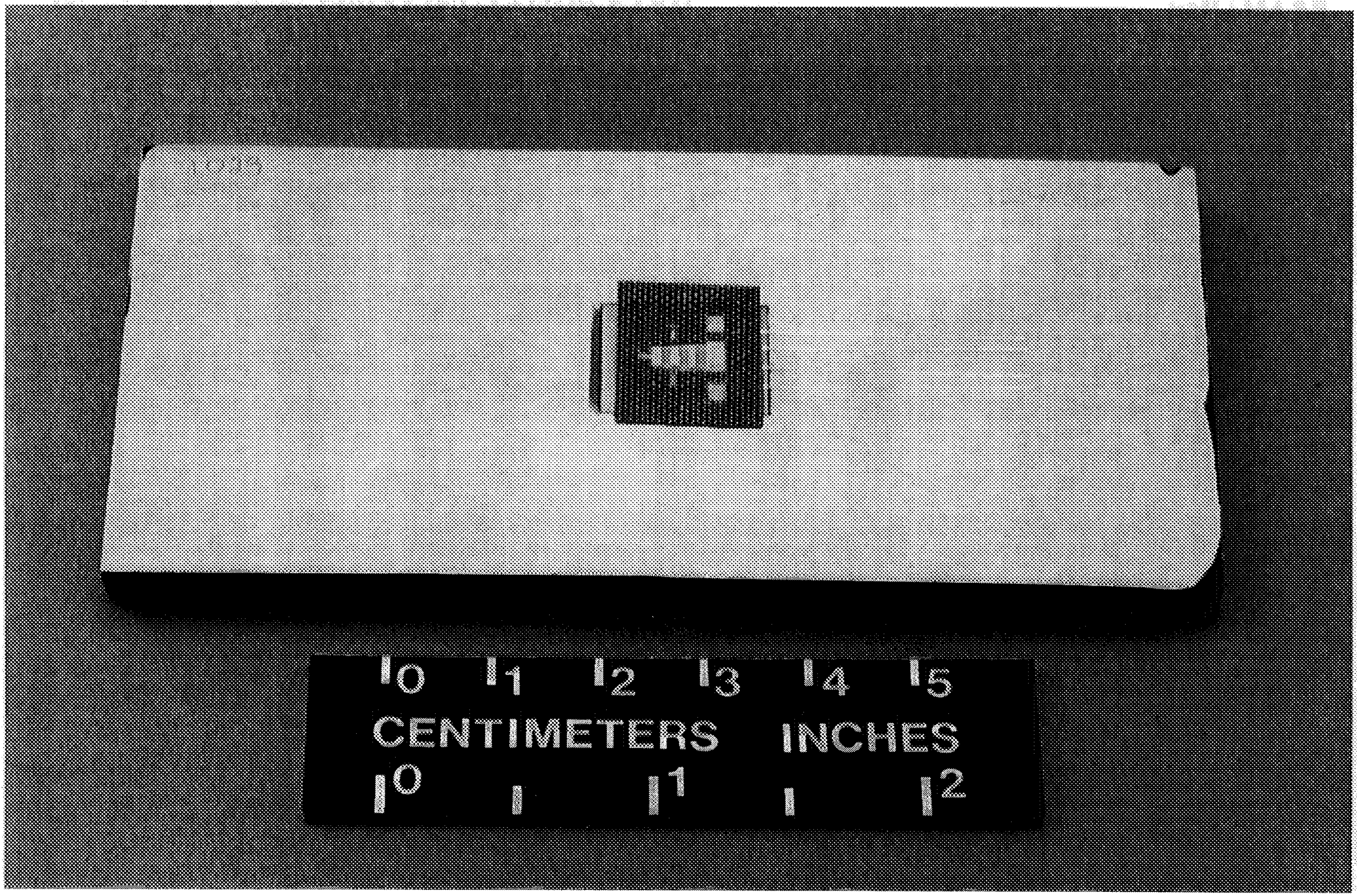
GAGE W/CARRIER PLACED ON BASECOAT **PHOTO #2**



CLOSE-UP OF GAGE READY FOR FLAME-SPRAYING **PHOTO #3**

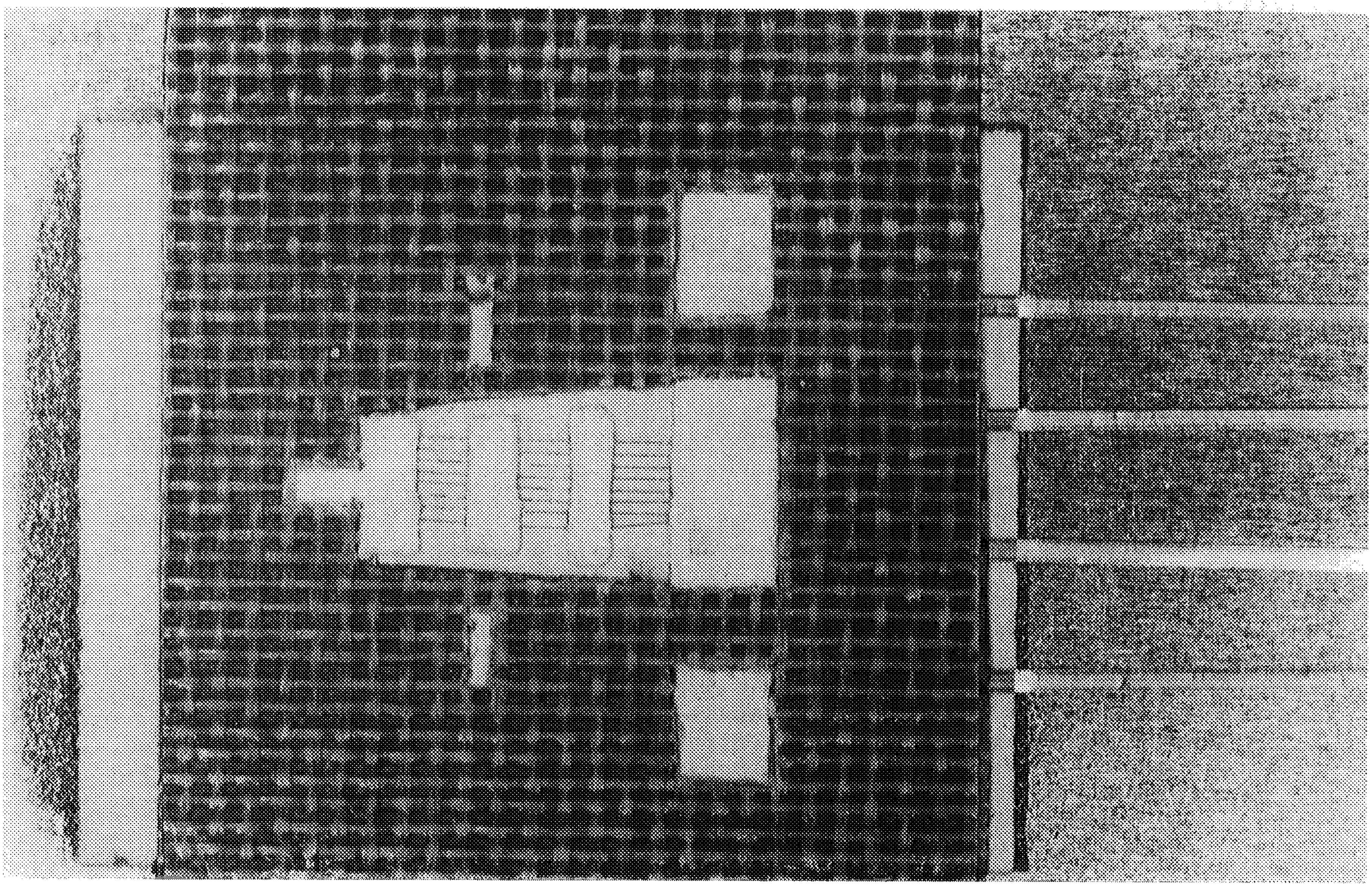


INITIAL FLAME-SPRAYING COMPLETED **PHOTO #4**



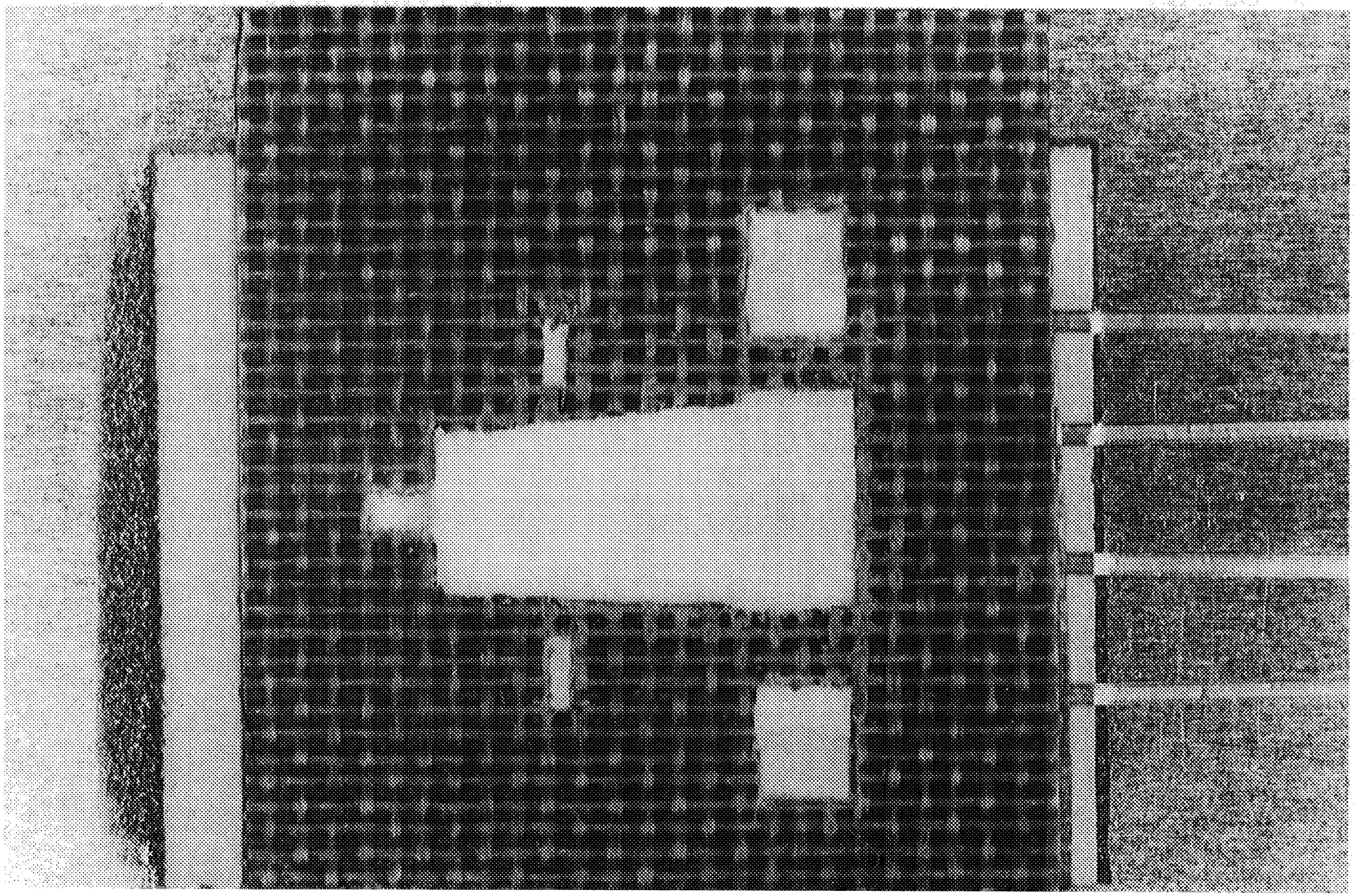
OVERVIEW W/TAPE SEGMENTS REMOVED FROM ACTIVE GAGE

PHOTO #5



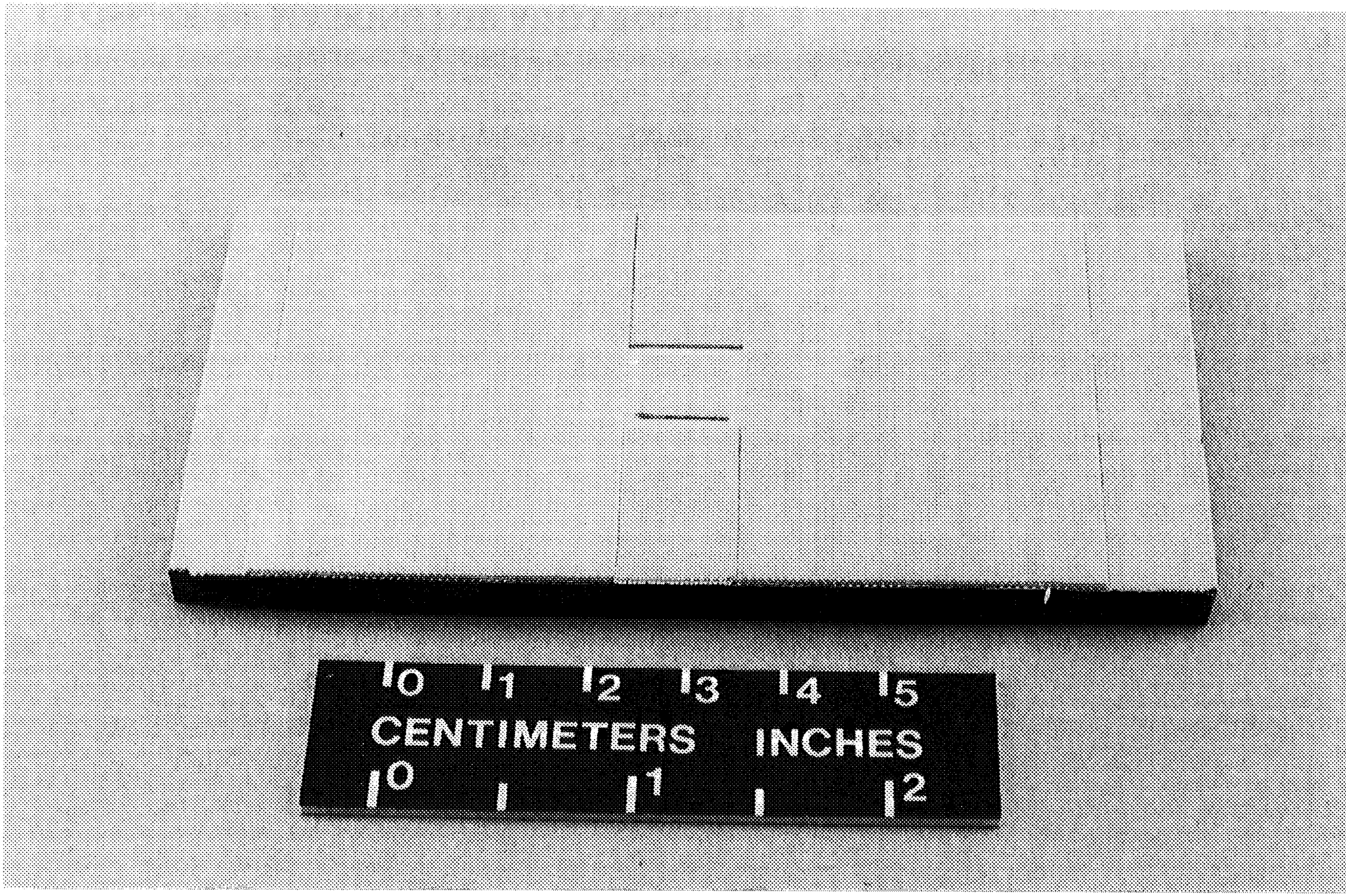
CLOSE-UP OF ACTIVE GAGE READY FOR FINAL FLAME-SPRAYING

PHOTO #6



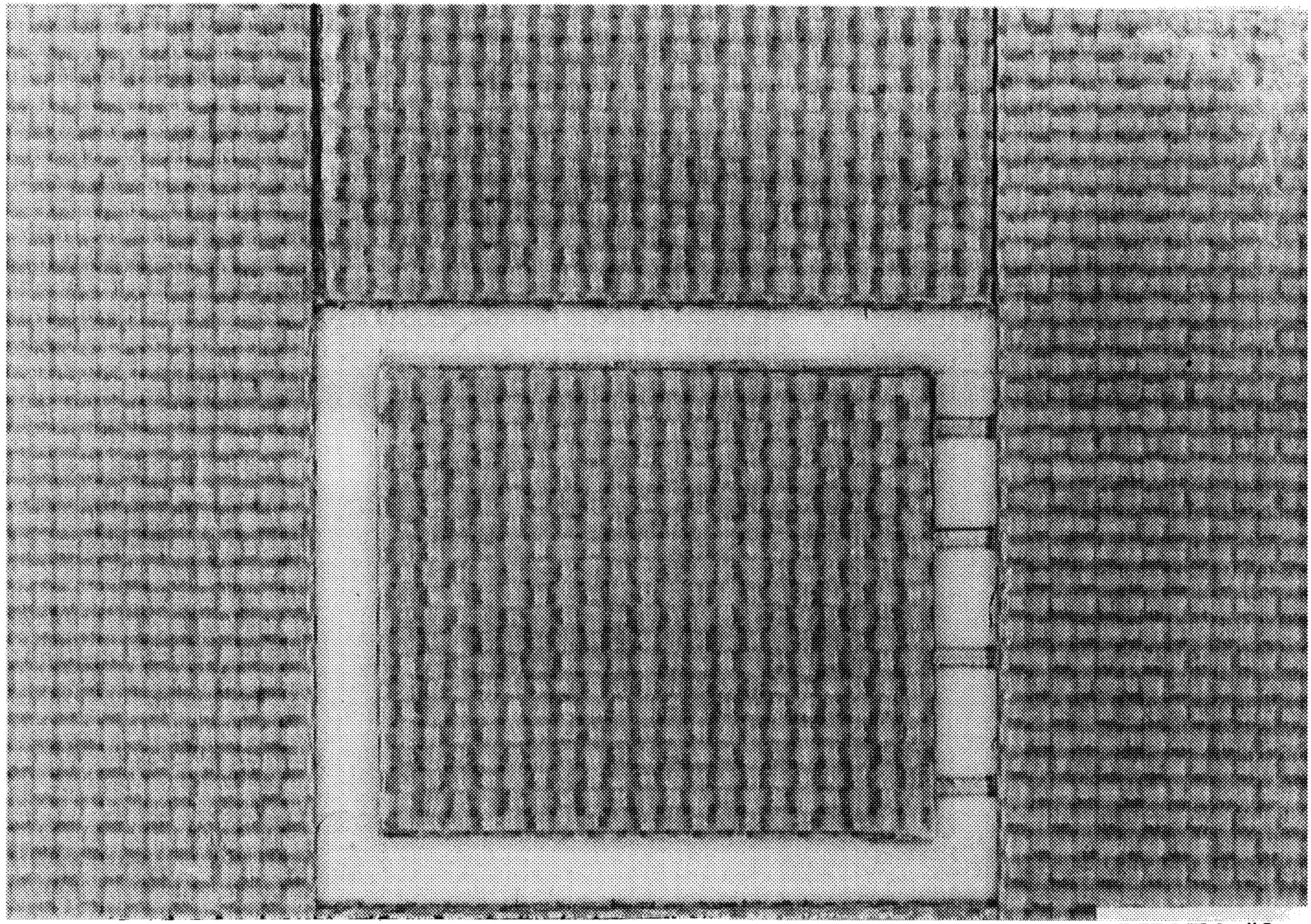
FINAL FLAME-SPRAYING OF ACTIVE GAGE AND TACK BONDING OF COMPEN. GAGE COMPLETED

PHOTO #7



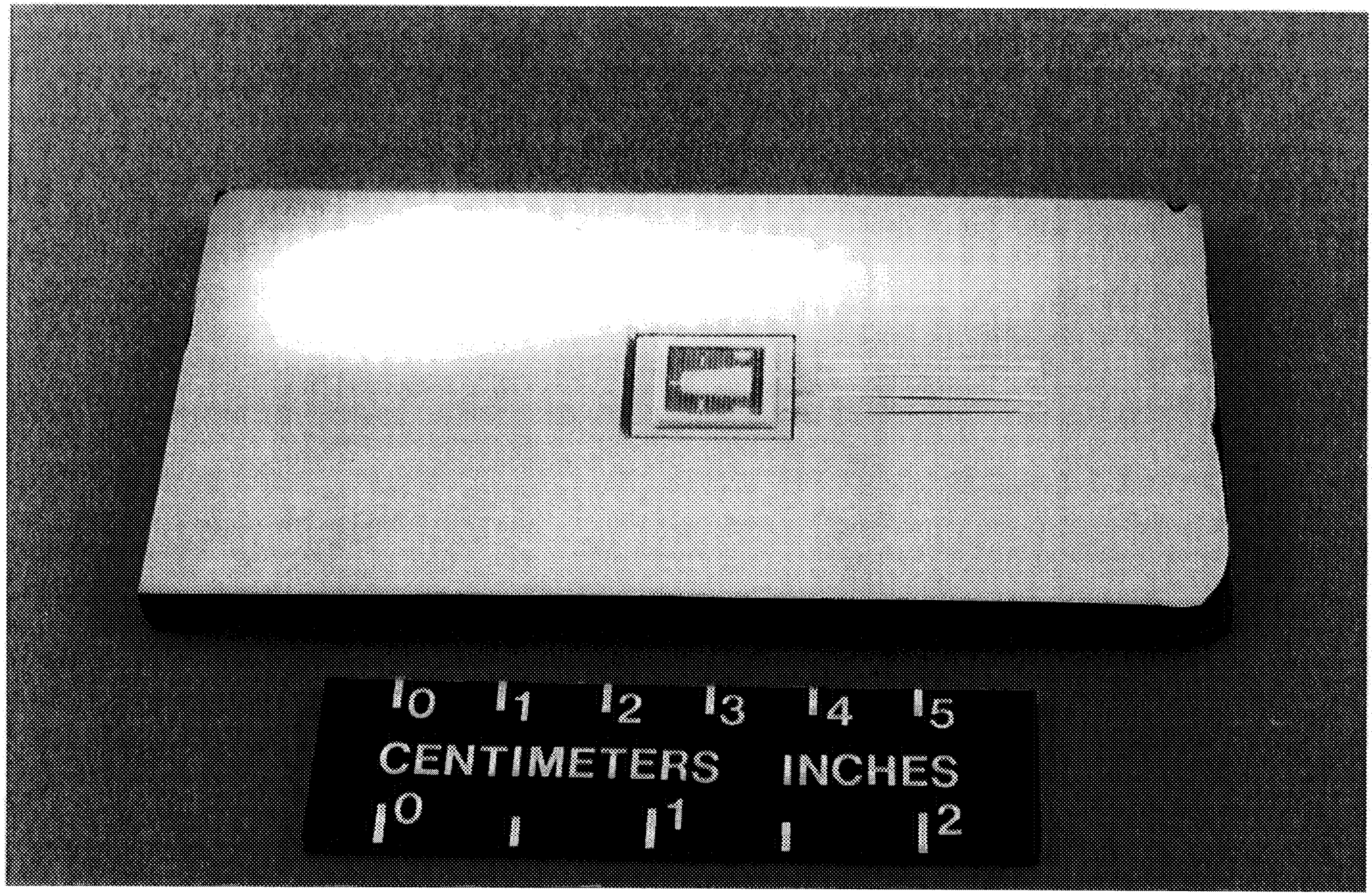
REMASKING FOR FLAME-SPRAYING OF
THERMAL BLANKET BORDER

PHOTO #8



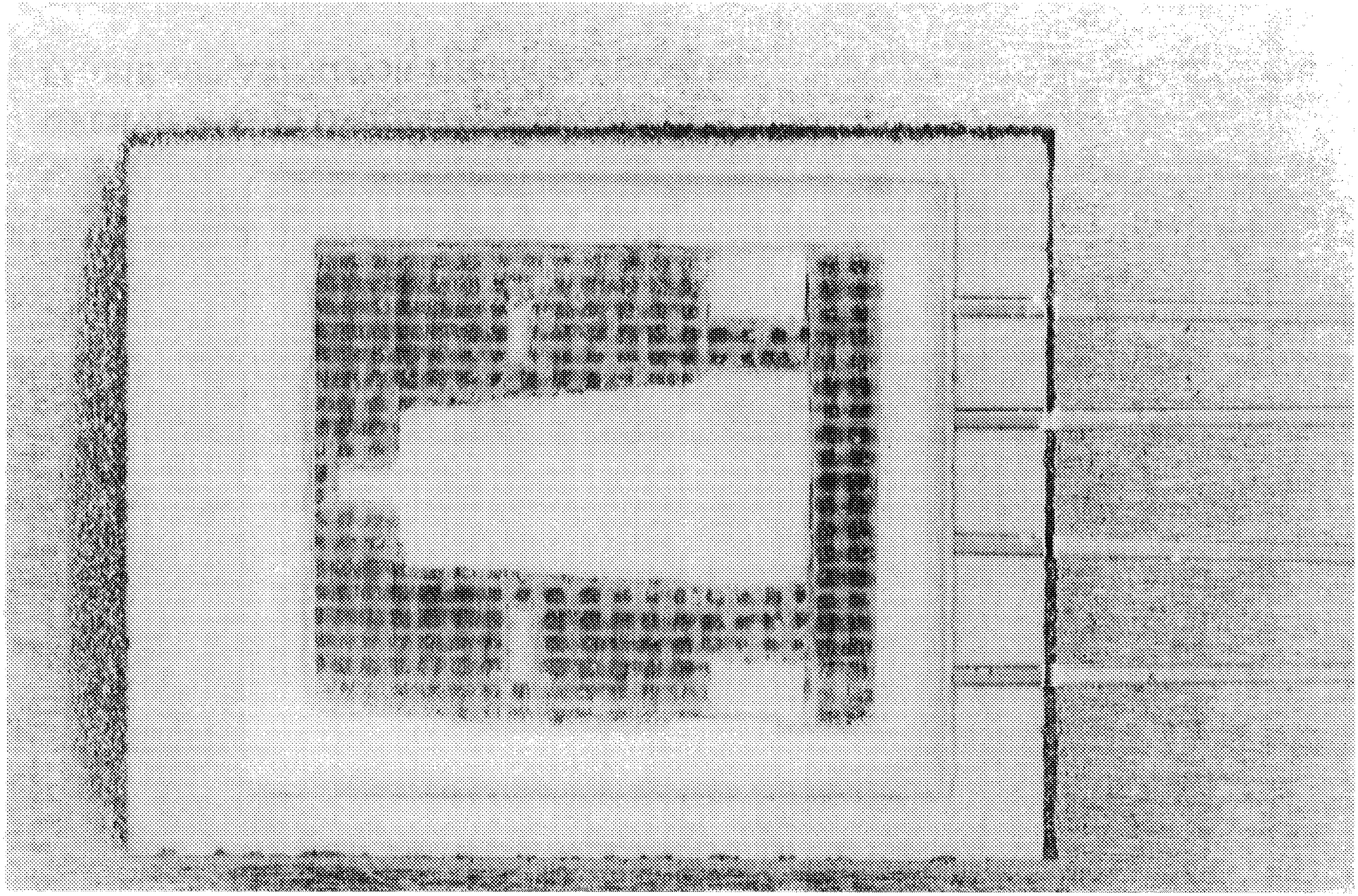
CLOSE-UP OF MASKING FOR Al2O3 BORDER

PHOTO #9

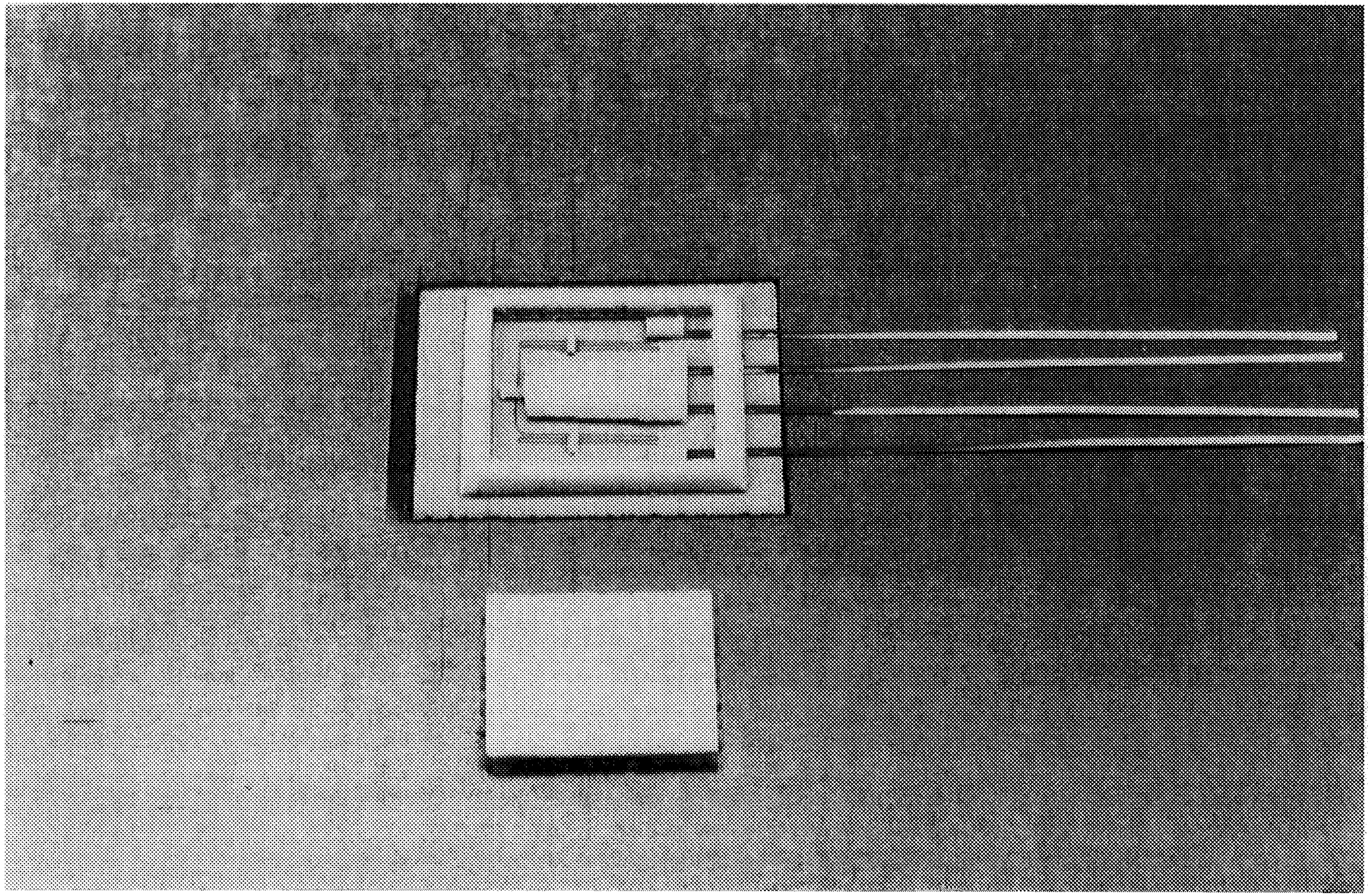


OVERVIEW FOLLOWING COMPLETION OF FLAME-SPRAYING FOR THERMAL BLANKET

PHOTO #10

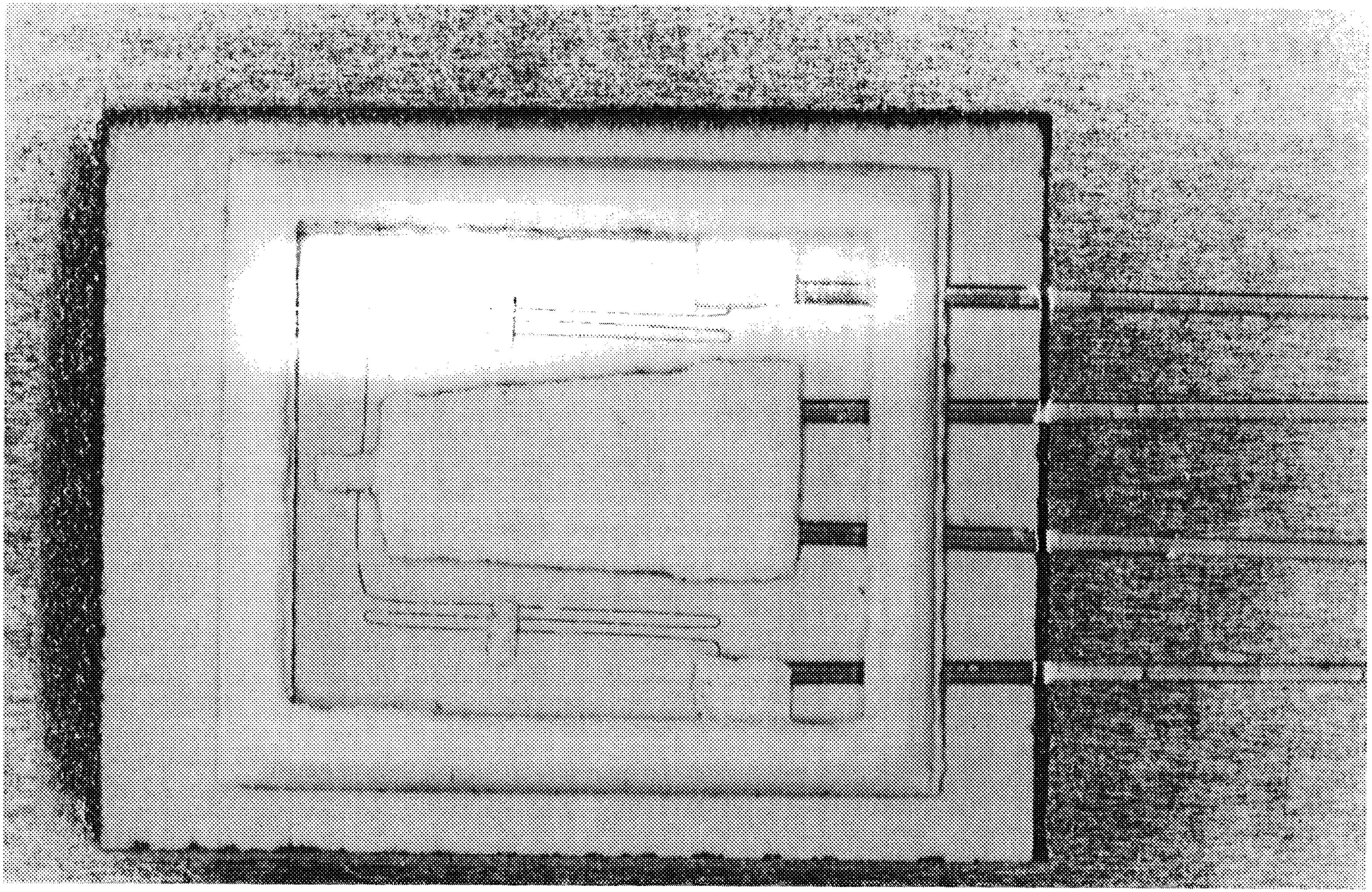


CLOSE-UP OF THERMAL BLANKET BORDER **PHOTO #11**



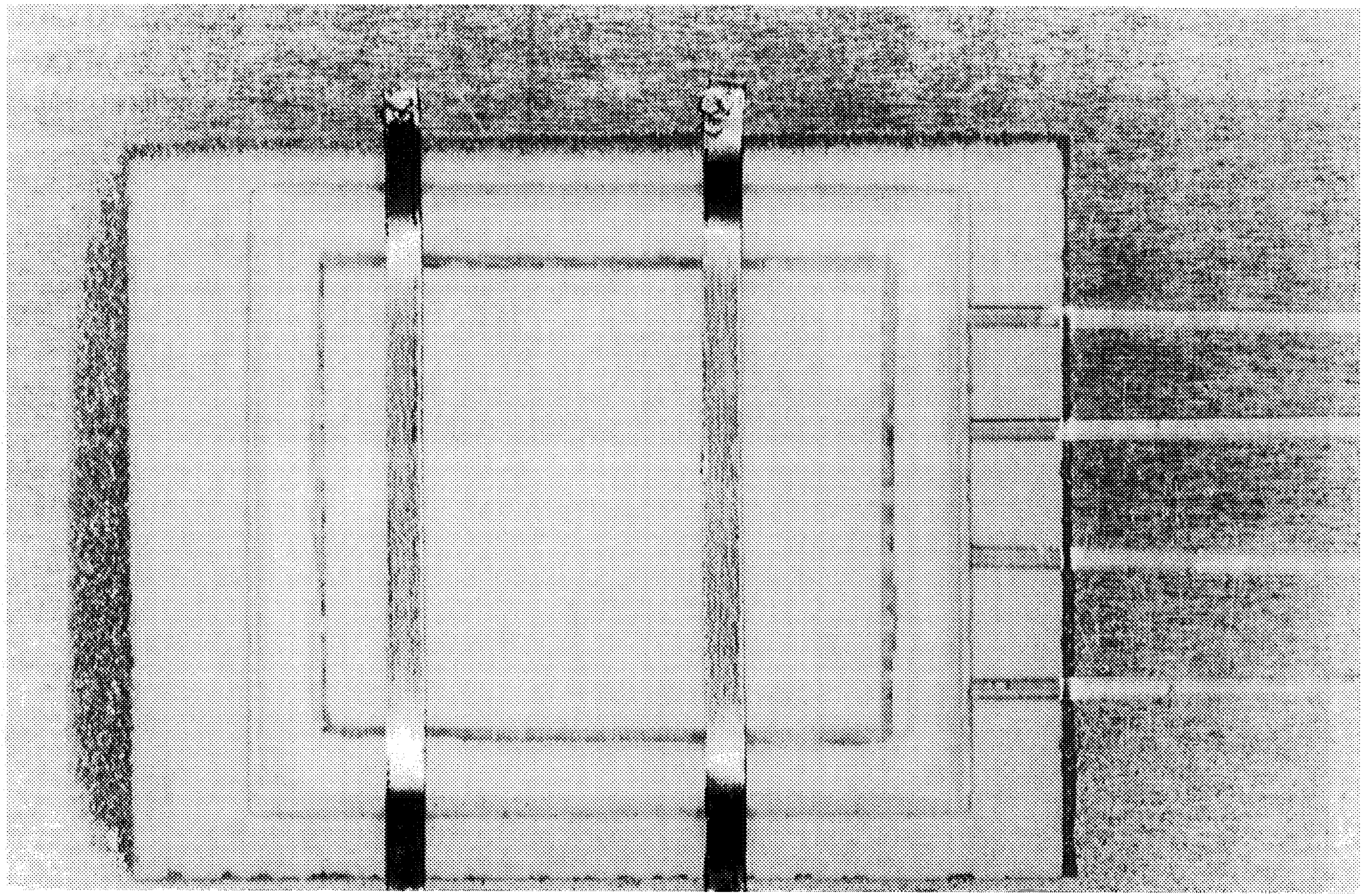
OVERVIEW OF GAGE W/COMPEN. ELEMENT EXPOSED
SHOWING THERMAL BLANKET READY FOR INSTALL.

PHOTO #12



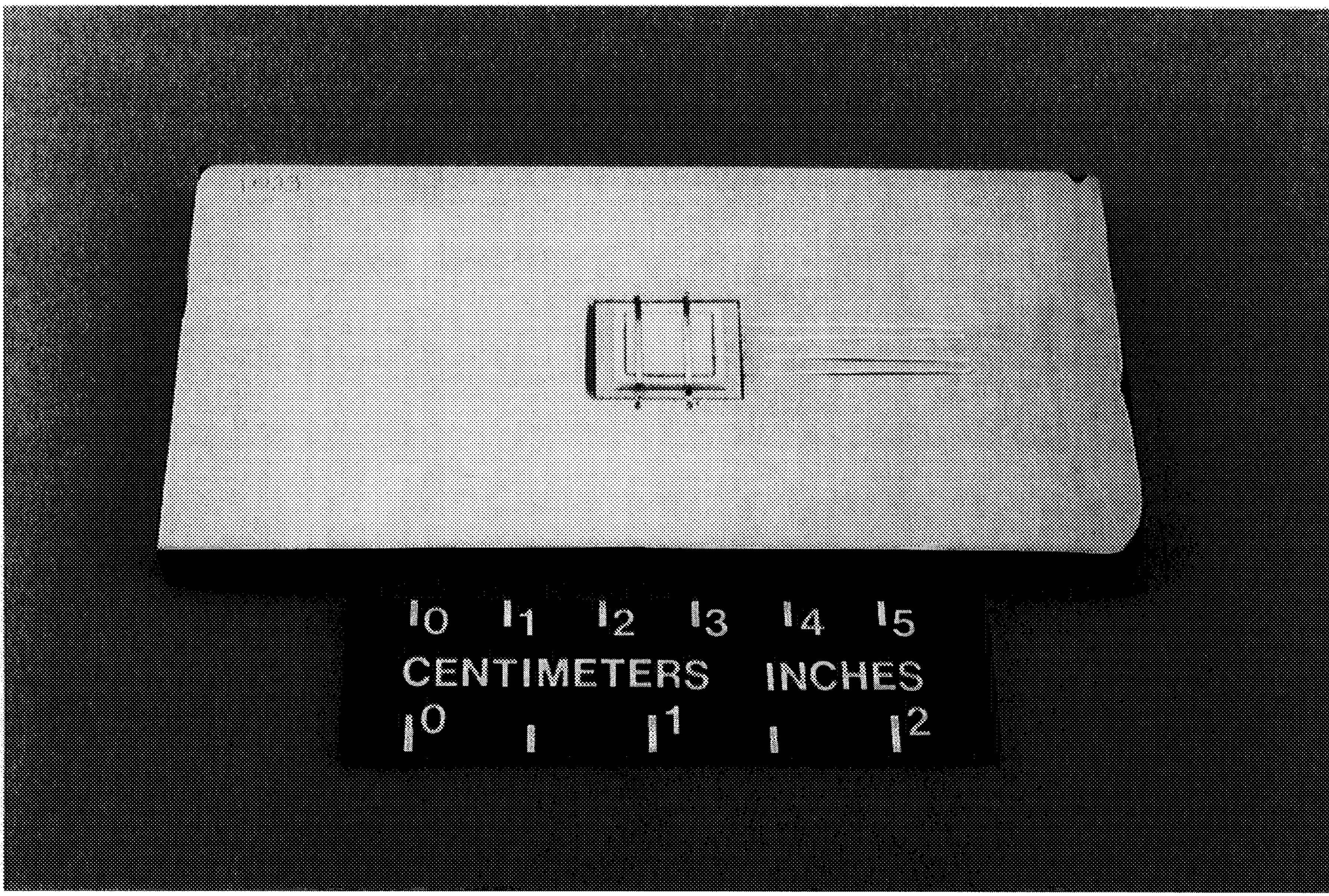
CLOSE-UP OF INSTALLED GAGE ELEMENTS
READY FOR THERMAL BLANKET INSTALLATION

PHOTO #13



CLOSE-UP OF COMPLETED GAGE INSTALLATION W/THERMAL BLANKET HELD IN PLACE W/STRAPS

PHOTO #14



OVERVIEW OF COMPLETED GAGE INSTALLATION
READY FOR LEADWIRE HOOK-UP

PHOTO #15

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13. ABSTRACT *(Maximum 200 words)*

The NASA Langley Research Center uses more than 10,000 stain gages per year in supporting its various research programs. The character of the testing at LaRC is such that the types of strain gage installations, the materials they are applied to, and the test environments encountered, require many varied approaches for installing strain gages. These installations must be accomplished in the most technically discerning and appropriate manner. This technical memorandum is offered as an assisting guide in helping the strain gage user to determine the appropriate approach for a given strain gage application requirement. Specifically, this document offers detailed recommendations for strain gaging the following: **LaRC-Designed balances, LaRC custom transducers, certain composite materials and alloys, high-temperature test articles, and selected non-typical or unique materials or test conditions.**

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